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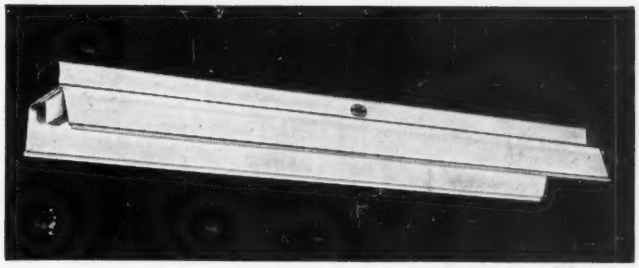

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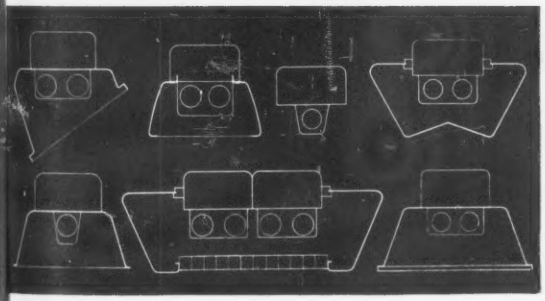

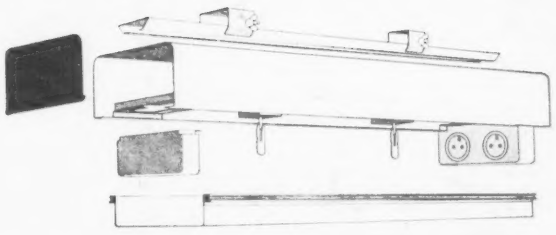

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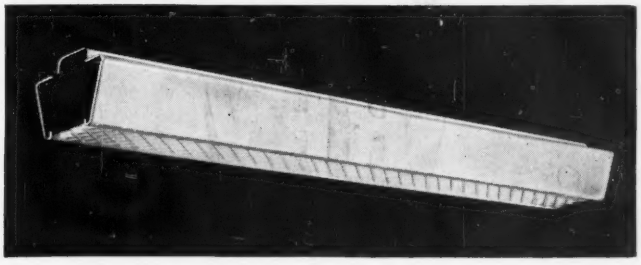

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Light and LIGHTING

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Close of an Epoch

IT would be strange if we could take up the editorial pen this month without a special feeling of satisfaction. With this issue the fiftieth volume of our journal is completed. It is understandable that, on this account, we should introduce it with something of that pleasurable sense of achievement which elates not only the successful athlete and the record-breaker but also those who have a long record of good service to their credit. Like other journals, ours has had its vicissitudes, but we hope our readers will agree that it is now in its prime. In the Golden Jubilee number, to be published next month, the progress of the lighting art and of lighting practice during the half century now drawing to its close will be reviewed. It has been the function and privilege of *Light and Lighting* to report this progress in detail while it was happening, and the journal will continue to keep its readers well informed in the future. It is, of course, to the interest and practical support of subscribers and advertisers that this journal—like others—owes its continuance. This is a fitting occasion on which to express our thanks to these supporters, to whom we have tried to give good service, as well as to the many contributors whose articles and notes have been published in our pages. With these thanks we couple good wishes for enjoyment of the approaching annual festival of goodwill.

Notes and News

WE recently sent a questionnaire to some 200 of our readers who were selected quite at random irrespective of who they were, what they did or where in the world they lived. The object of the questionnaire was to find out whether we are giving readers the kind of thing they want and in which way we could improve our service.

We would like first to thank all those who contributed to this public opinion poll. We received a lot of compliments which we were not seeking—though they were none the less pleasing—but we also received some very useful criticism and comment all of which we intend to consider most carefully and some of which we have already incorporated into our plans for the future. Many who completed the questionnaire went to considerable trouble for which we are grateful.

Apart from suggestions on editorial content some most interesting information came out of the replies. For example we find that less than 30 per cent. of our readers can be described as being in the lighting industry and over 70 per cent. are people who want to keep up-to-date with lighting developments and application. Another interesting fact is that on the average every copy of *Light and Lighting* is read by seven people. We present these facts as facts though some one with a greater aptitude than us for publicity could no doubt make something very useful out of them.

Of the comments on editorial content the most common one was a desire for more information on new products, particularly technical details of new fittings. This is something we intend to pursue. We are, of course, largely dependent on the manufacturers to give us the information we want and strange though it may seem they are not always aware of the facility we offer them to announce their wares to the people who are so anxious to know about them. Many manufacturers, quite properly, regard a " mention " as publicity for themselves; our policy has always been to put service to the reader first. We do not confuse editorial mention with advertising; if a manufacturer has something new which will interest readers we will say so—provided the manufacturer gives us the information readers want. We want to serve both the industry and readers and we think we do it better than most trade and technical journals.

As for the advertisements we carry, many who replied to our questionnaire mentioned the value of these. One of the advantages of *Light and Lighting* is that it does not carry an overwhelming number of advertisement pages so that the ads. are as much a part of the journal as the editorial pages. It is our intention to continue this policy for even if we managed to double the amount of advertising we are so full of ideas for editorial that the balance would still be preserved.

Association Belge de l'Eclairage Public

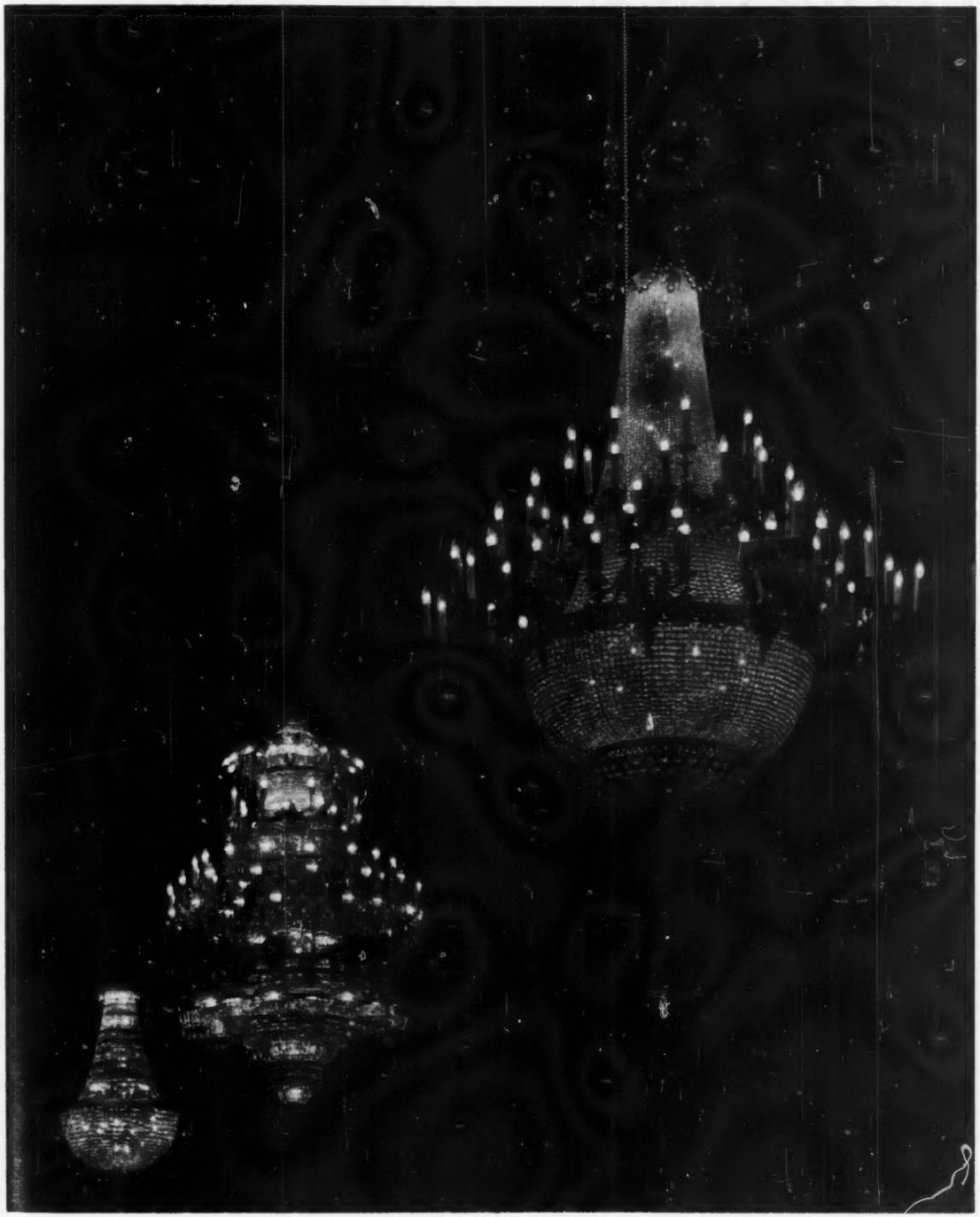
The first Conference of the Association Belge de l'Eclairage Public took place in Brussels recently under the presidency of M. Andre Boereboom and was opened by the Minister of Public Works. This new association now has a membership of over 200 and is already doing useful work in improving street lighting in Belgium, particularly amongst the smaller authorities.

M. Boereboom in his presidential address, and other speakers during the two-day meeting, referred to the difficulties faced by the smaller authorities who until recently had no central source to whom they could apply for guidance and information which is now one of the functions being undertaken by the ABEP. The cost of street lighting naturally came into the discussions and M. Jules Schreder put forward some ideas for increasing spacing which would reduce both capital and running costs; he also stressed the importance of planned maintenance schemes and group replacement of lamps. Other papers dealt with the Belgian street lighting code, the lighting of public buildings and collaboration between neighbouring authorities to secure some measure of uniformity in lighting.

As a meeting of the CIE Working Committee on street lighting had been arranged in Brussels at the same time, a number of overseas visitors were able to be present and take part in the discussions.

50 Up

This issue brings us to the end of another volume and completes our half-century. Our next issue will be a special one to commemorate our Golden Jubilee. As a result, Mr. Penny's review of the past year, which is usually the main feature of the January issue, will be held over until February.



As the main feature in this issue is concerned with fluorescent lamps we thought we would show by way of contrast in our frontispiece something which even the fluorescent lamp cannot do.

FLUORESCENT TUBE GUIDE

By W. A. R. Stoyle, B.Sc., A.M.I.E.E., and A. G. Brown, Dip.M.I.E.S.

Many papers and articles have been published on fluorescent tubes, circuits, auxiliary gear and their general and specialised application. Much of the value of this material, however, is lost because of the difficulty of referring to so many publications. An attempt to summarise the many and varied aspects of this subject was made in a paper presented to the Illuminating Engineering Society in 1949, but the information contained in that paper is, inevitably, now out of date. This article has therefore been prepared to fill the need for a review of existing theory and practice. In order to make the article of value to the "newcomer" to fluorescent lighting as well as to the practised "hand," some of the fundamental information contained in the original paper has been included.

The electrical contractor and lighting engineer have a difficult task in keeping abreast of the rapid technical advances in fluorescent lighting. The wide range of tube sizes, wattages and colours in combination with a multiplicity of circuits and an ever increasing variety of associated auxiliary gear may well confuse even the specialist. This "guide" is intended as a factual survey and it avoids those points of controversy which inevitably accompany any new "art," as the practice of fluorescent lighting certainly is. The subject divides itself naturally into three main parts: (1) tubes, (2) circuits and (3) testing and maintenance. A reasonable knowledge of the first two is more than helpful in the practice of the third.

Whilst every effort has been made to provide data in accordance with the most recent information available from different manufacturers, it must be pointed out that changes, particularly in regard to the light output of tubes, are continually being made.

PART 1: THE FLUORESCENT TUBULAR LAMP

(1) Construction of the Fluorescent Tube

The fluorescent tube consists essentially of a clear glass tube with electrodes sealed into the ends, the tube being coated internally with a fluorescent powder. The electrodes generally consist of a coiled filament similar to those used in ordinary tungsten lamps, coated with a mixture of rare-earth oxides to provide a copious electron emission under operating conditions. These electrodes may, in some cases, have small metal plates in close juxtaposition which act as anodes on alternate half cycles, but in others the lead-in-wires act as anodes. Fig. 1 shows the electrode construction in a typical 5 ft. 80-watt tube.

The tube is filled with a very low pressure of mercury and a small amount of argon to facilitate starting. The design of the tube is such that wall operating temperature is well below a value which would result in any physical or chemical change in the fluorescent coating.

Since the electrodes generally require preheating before the lamp strikes, both ends of each electrode are connected to double contact caps, bayonet or bi-pin caps being used for the 8 ft. 125-watt and 5 ft. 80-watt tubes and bi-pin caps for 4 ft. 40-watt and smaller tubes.

Mr. Stoyle is with the General Electric Co. Ltd., and Mr. Brown is with Philips Electrical Ltd.

(2) Operation of the Fluorescent Tube

The chief characteristic of a low-pressure discharge is that a considerable part of the radiated energy, actually about 50 per cent. of the wattage input to the tube, is emitted at a wavelength of 2,537 Angstrom units. Some of this radiation is converted into visible, continuous radiation by the fluorescent coating, the remainder emerging as heat, conducted, convected or radiated. The proportion of ultra-violet energy converted into visible radiation depends on the converting "efficiency" of the particular "phosphor" used. Fig. 2 shows the manner in which the input energy of a typical 80-watt tube is dissipated.

The efficiency of generation of ultra-violet radiation at 2,537 Å has an optimum value at a relatively low current density, which means that in a tube of say 1½ in. diameter, the tube current, tube wattage and hence total luminous output is somewhat restricted. Even at such a low current, however, the wattage dissipated in a given tube could be increased by using very long tubes but here a restriction is imposed by the available supply voltage. The choice of dimensions of commercially available tubes is, therefore, a compromise between the various factors mentioned above.

In a fluorescent tube, part of the input energy is dissipated in the electrodes, the remainder being dissipated in

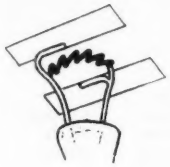


Fig. 1. Electrode construction.

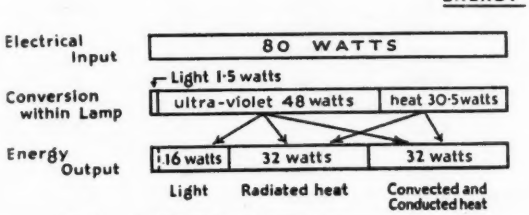


Fig. 2. Dissipation of input energy of typical 80-watt tube.

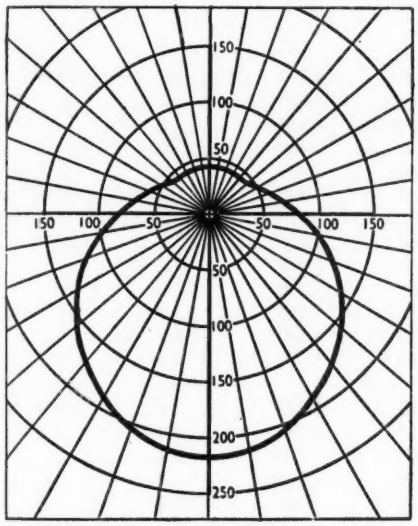


Fig. 3. Polar diagram for 40-watt reflector type tube MCFR/U (Natural colour) showing candelas per 1,000 lumens total flux.

the discharge itself, the latter being responsible for the luminous radiation ultimately emitted. Increase in the length of a fluorescent tube will thus increase the ratio of arc watts to total watts and hence the overall efficiency will be increased, but here again, we are limited by the voltage of the supply mains.

The particular colour of the light emitted by the fluorescent tube is largely dependent on the particular phosphor employed. Up to 1947 a substantially white light was produced from a mixture of phosphors but the development of the calcium halophosphates provided a range of "near white" colours of much enhanced efficiency and improved lumen maintenance in a single powder. Apart from these "near white" tubes it has not been possible so far to produce a very saturated colour; such tubes generally incorporate a coloured pigment in addition to the phosphor.

(3) The Range of Fluorescent Tubes

(3.1) *Standard Tubes*

A large variety of standard fluorescent tubes are available from the 8 ft. 125-watt down to the 18 in. 15-watt, details and dimensions of which are shown in Table 1. These are available in various colours as indicated in Table 2(a).

All 18- and 24-in. tubes may be operated singly on 100/130 volt supplies or two in series on 200/250 volts. In addition, the 18 in. 15-watt and 24 in. 20-watt tubes may be operated singly on 200/250 volts in suitable circuits, but operation of 24 in. 40-watt tubes singly on 200/250 volts is not recommended because of the large choke which would be necessary and its high wattage loss.

All the straight tubes, with the exception of the special internally striped tube, may also be obtained with an external "silicone" finish or external metal stripe for use on instant start circuits as described in Part 2.

Miniature tubes, details of which are given in Table 2(b), are also available for special applications.

(3.2) *Reflector Type Fluorescent Tubes (Type MCFR/U)*

Reflector type tubes are at present made in two ratings, 4 ft. 40-watt and 5 ft. 80-watt In these tubes a thin layer of titanium dioxide extends over about two-thirds of the internal circumference of the tube, the fluorescent coating being subsequently applied. This arrangement gives a considerable increase in downward light as indicated in the polar diagram in Fig. 3. The ratio of brightness of the "window" to the reflecting surface of the tube is about 6:1 and the absorption of the reflecting coating is about 10

Table 1
Dimensions of fluorescent tubes

Tube (wattage)	125*	80	80	50	40	30	40	20	15
Nominal Overall Length (inches)	96±0.25	60	60±0.25	60	48	36	24	24	18
Diameter (mm.)	38±1.5	26±1	38±1.5	26±1	38±1.5	26±1	38±1.5	38±1.5	26±1
Cap	BC	Bi-pin	BC	Bi-pin	Bi-pin	Bi-pin	Bi-pin	Bi-pin	Bi-pin
Length, including pins at both ends (max.) (inches)	—	59.615	—	59.615	47 $\frac{15}{32}$	35 $\frac{15}{32}$	23 $\frac{15}{32}$	23 $\frac{15}{32}$	17 $\frac{15}{32}$
Length, including pins at one end only (inches)	—	59.24 min. 59.335 max.	—	59.24 min. 59.335 max.	47 $\frac{1}{2}$ + 0—$\frac{5}{32}$	35 $\frac{1}{2}$ + 0—$\frac{5}{32}$	23 $\frac{1}{2}$ + 0—$\frac{5}{32}$	23 $\frac{1}{2}$ + 0—$\frac{5}{32}$	17 $\frac{1}{2}$ + 0—$\frac{5}{32}$
Length, excluding pins (max.) (inches)	—	59.055	—	59.055	47 $\frac{7}{32}$	35 $\frac{7}{32}$	23 $\frac{7}{32}$	23 $\frac{7}{32}$	17 $\frac{7}{32}$

* Now also available with bi-pin caps, overall length 94.06 ins.

Table 2(a)

Nominal efficiencies and average life of fluorescent tubes

Tube Rating	Colour	Efficiency Lm/W		Light output (lumens)		Approx. Brightness (Candelas per sq. in.) (100 hours)	Average Life (hours)
		Initial (100 hours)	Average through-out life	Initial (100 hours)	Average through-out life		
8 ft. 125-watt	Daylight	61	54	7,625	6,750	5.7	5,000
	Natural	51	43	6,375	5,375	4.8	,,
	Warm White	63	56	7,875	7,000	5.9	,,
	White	64	57	8,000	7,125	6.0	,,
5 ft. 80-watt	Daylight	57	51	4,560	4,080	5.7	5,000
	Natural	46	40	3,680	3,200	4.6	,,
	Deluxe Warm White	40	33	3,200	2,640	4.0	,,
	Warm White	59	53	4,720	4,240	5.9	,,
	White	60	54	4,800	4,320	6.0	,,
	Colour Matching	44	38	3,520	3,040	4.4	,,
5 ft. 50-watt	Natural	48	41	2,400	2,050	4.2	5,000
4 ft. 40-watt	Daylight	61	55	2,440	2,200	3.6	5,000
	Natural	48	42	1,920	1,680	3.0	,,
	Deluxe Warm White	42	36	1,680	1,440	2.6	,,
	Warm White	63	57	2,520	2,280	3.9	,,
	White	64	58	2,560	2,320	3.9	,,
	Colour Matching	46	40	1,840	1,600	2.8	,,
3 ft. 30-watt	Daylight	57	49	1,710	1,470	5.2	5,000
	Natural	46	39	1,380	1,170	4.2	,,
	Deluxe Warm White	40	32	1,200	960	3.7	,,
	Warm White	59	51	1,770	1,530	5.4	,,
	White	60	52	1,800	1,560	5.5	,,
	Colour Matching	43	36	1,290	1,080	3.9	,,
2 ft. 40-watt	Daylight	39	33	1,560	1,320	5.2	5,000
	Natural	33	27	1,320	1,080	4.4	,,
	Deluxe Warm White	26	19	1,040	760	3.4	,,
	Warm White	42	34	1,680	1,360	5.6	,,
	White	42	34	1,680	1,360	5.6	,,
2 ft. 20-watt	Daylight	45	40	900	800	3.0	5,000
	Natural	38	32	760	640	2.5	,,
	Deluxe Warm White	31	23	620	460	2.1	,,
	Warm White	50	45	1,000	900	3.3	,,
	White	50	45	1,000	900	3.3	,,
	Colour Matching	36	31	720	620	2.4	,,
18 in. 15-watt	Daylight	44	37	660	555	4.5	5,000
	Natural	35	28	525	420	3.6	,,
	Deluxe Warm White	30	22	450	330	3.1	,,
	Warm White	44	36	660	540	4.5	,,
	White	42	34	630	510	4.3	,,
	Colour Matching	31	25	465	375	3.2	,,
Circle 40-watt	Deluxe Warm White	40	32	1,600	1,280	2.6	2,500
5 ft. 80-watt	Red	4	—	—	—	0.2	5,000
	Yellow	30	—	—	—	2.4	,,
	Green	50	—	—	—	5.6	,,
	Blue	14	—	—	—	1.4	,,

'Daylight' is also specified as 'Cool White' and 'Natural' as 'Warm White.'

Table 2(b)
Miniature fluorescent tubes

Class and Rating	Colour	Initial Efficiency, Lm/w	Nominal overall length, inches	Nominal Diameter	Cap
MCF/U 4-watt	Warm White Cool White	25 23	6	$\frac{5}{8}$ in.	Miniature Bi-pin
MCF/U 6-watt	Warm White Cool White	38 35	9	$\frac{5}{8}$ in.	Miniature Bi-pin
MCF/U 8-watt	Warm White Cool White	46 41	12	$\frac{5}{8}$ in.	Miniature Bi-pin

Table 3
Characteristics of reflector tubes

Tube Rating	Colour	Initial Brightness cd/sq.in.		Approximate Total flux (lumens) Average through life	Max. Intensity (Candelas)
		Gap	Reflector		
4 ft. 40-watt	Daylight	7.1	1.3	1,830	390
5 ft. 80-watt	Daylight	11.3	2.0	3,670	625
5 ft. 80-watt	Warm White	11.8	2.1	3,810	650

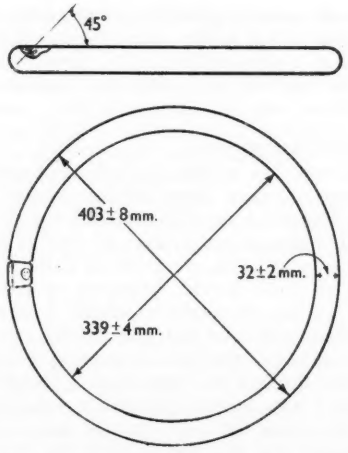


Fig. 4. 40-watt circular fluorescent tube.

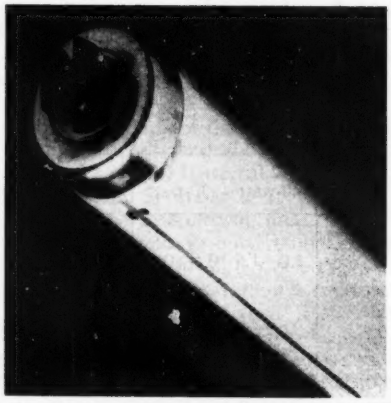


Fig. 5. Cap for internal striped tube type MCFB/U.

per cent. Dimensions and electrical characteristics are identical with standard tubes.

General technical data on 4 ft. 40-watt and 5 ft. 80-watt reflector tubes are given in Table 3.

These reflector tubes are primarily intended for simple fittings of the batten type. Their use tends to reduce maintenance costs as the efficiency of the internal reflector is maintained despite the presence of dust and dirt on the upper surface of the tube.

(3.3) *Circular Fluorescent Tubes*

Designed for decorative as well as utilitarian appeal, the 40-watt circular fluorescent tube has similar electrical characteristics to the straight 40-watt tube but is some $\frac{1}{4}$ in. less in diameter. Dimensional details are shown in Fig 4; the gap between the ends of the lamp is filled by a special 4-pin plastic cap thus completely closing the circle. This lamp is available in only one colour (Deluxe Warm White) as its principal application is in the domestic or commercial sphere. The initial efficiency is 40 lumens per watt and the average efficiency throughout life is 32 lumens per watt. The tube is siliconed for instant start purposes and may be operated on the normal type of circuit or with a tungsten filament lamp as ballast, as described in Section (10). The rated average life is 2,500 hours.

A 32-watt circular tube with a diameter of 12 inches and using a similar cap is also available.

(3.4) *Cold Starting Fluorescent Tubes*

Designed for operating in series with a tungsten ballast lamp without any auxiliary gear, "cold starting" tubes employing an internal conducting starting stripe known as type MCFB/U are available in the 4 ft. 40-watt rating. The internal stripe may be connected to one electrode, or alternatively two stripes may be connected one to each electrode separated by a small gap across which ionisation of the gas occurs at starting. Such lamps are generally fitted with a special type of insulated cap to minimise the possibility of electric shock if one cap is inserted into a "live" fitting when the other end is held in the hand. Such a cap is shown in Fig 5.

The average life of the "cold starting" tube will,

naturally, be less than the normal tube started by pre-heat methods. In addition, due to the inevitable wattage loss in the internal stripe, the luminous efficiency is somewhat below that of the standard type of tube.

(4) Characteristics of the Fluorescent Tube

The principal factors with which the maintenance engineer is concerned are life and light output and (since these depend on the tube being operated at its correct wattage) its electrical characteristics. In this section these and other subsidiary characteristics are described.

(4.1) *Luminous Output and Efficiency*

The light output of a fluorescent tube decreases during life for a variety of reasons. Principal amongst these are the deposition of a film of mercury on the fluorescent coating and direct chemical attack.

During the first 100 hours or so the light output falls off more rapidly but after this initial drop the decline is gradual. (At the end of normal rated life the light output is still some three to four times that of a filament lamp of equivalent wattage.) The relationship between efficiency and life for a typical 5 ft. 80-watt tube is shown in Fig. 6. The shape of the maintenance curve is such that the "average value throughout life" can be taken as the actual values at 2,000 hours, assuming an objective average life of 5,000 hours. The fall in light output is not generally accompanied by any noticeable change in the colour of the light.

"Initial" efficiencies are always quoted at 100 hours for the reasons stated above, but for service and design calculations the average throughout life figure is generally taken. Table 2 indicates the initial and average throughout life efficiency and lumen output for the complete range of standard fluorescent tubes.

(4.2) *Life*

Apart from accidental failures such as glass cracks, etc., the ultimate failure of the tube is caused by exhaustion of the electron emissive material with which the filamentary electrodes are coated, this material being progressively disintegrated throughout life. A very slight momentary loss occurs each time the tube is switched on; thus the number of switchings during the life of a tube has some influence on its life. However, the rated average life should easily be achieved with an average of three to four hours per switch, but if this number of switchings is greatly exceeded a shorter life may result.

The present rated average life of the fluorescent tubes shown in Table 2 is 5,000 hours with the exception of the 40-watt circular tube which is 2,500 hours. These values refer to operation on alternating current circuits, but on direct current the life should not be substantially less provided polarity reversal is employed. Great advances in the uniformity in life of fluorescent tubes have been made in recent years.

Throughout the life of the tube the gradual disintegration

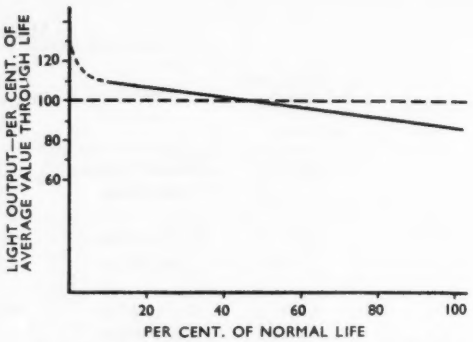


Fig. 6. Typical light maintenance curve for a fluorescent tube.

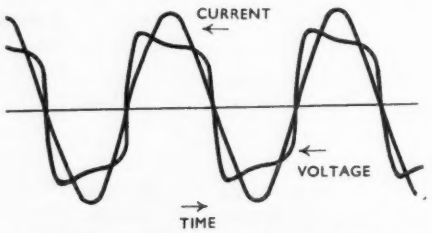


Fig. 7. Fluorescent tube current and voltage waveforms on 50 cycle supply.

of the electrode coating generally causes slight blackening over one or two inches at the ends. Premature or excessive end blackening is generally due to abnormal operating conditions the reasons for which are discussed fully in Section (19).

(4.3) *Electrical Characteristics*

Once the tube has started the voltage across it should not be much more than about 50 per cent. of the mains voltage. If this ratio is materially exceeded unstable operation will result. The approximate values of starting and running currents and tube voltages are given in Table 4.

The data in Table 4 refer primarily to tubes operated in inductive circuits but when operated in the capacitive circuit described in Section (9.2) the starting current is substantially the same as the normal running current.

The current through the tube itself is sensibly in phase with the applied voltage but, because the voltage wave form is distorted, the power factor of the tube alone to only about 0.9. The reason for this distortion is that the discharge current during each half cycle does not commence until the voltage has risen to a certain value (the striking voltage) and ceases to flow before the voltage falls to zero (the extinction voltage). An oscillogram of voltage and current is shown in Fig. 7.

The wattage in a fluorescent tube is thus the product of

Table 4
Electrical characteristics of fluorescent tubes

Lamp	8 ft. 125-watt	5 ft. 80-watt	5 ft. 50-watt	4 ft. 40-watt	4 ft. 40-watt (MCFB/U)*	2 ft. 40-watt	3 ft. 30-watt	2 ft. 20-watt	18 ins. 15-watt
Approx Tube Starting Current (amps)	1.0 1.6	1.0 1.6	0.5 0.75	0.5 0.75		1.0 1.6	0.4 0.65	0.4 0.7	0.4 0.65
Approx. Tube Running Current (amps)	0.91	0.85	0.41	0.41	0.5	0.88	0.34	0.35	0.3
Approx. Tube Volts	160±10	106±5	160±8	108±5	105±5	48±4	104±5	60±4	57±4

* Internal metal striped tube for tungsten ballast operation.

Table 5

Approximate mains current when power factor is corrected by means of the recommended capacitor

Lamp	Circuit	Approximate current (amps.)
8 ft. 125-watt	Single lamp	0.8
5 ft. 80-watt	Single lamp	0.5
	Twin lamp	0.8
4 ft. 40-watt	Single lamp. Inductive	0.25
	Twin lamp	0.4
3 ft. 30-watt	Single lamp. Inductive	0.18
	Twin lamp	0.33
2 ft. 40-watt	Two-in-Series	0.5
2 ft. 20-watt	Two-in-Series	0.25
	Single	0.15
1½ ft. 15-watt	Two-in-Series	0.18
	Single	0.12

tube current, tube voltage and tube power factor, e.g., taking the values for an 80-watt tube given in Table 4

$$0.85 \times 105 \times 0.9 = 80$$

Table 4 also shows that for operation from 200/250-volt mains, lamps of 3 ft. and above can only be operated singly but 18-inch and 24-inch lamps may be operated two in series.

(4.4) *Power Factor*

The use of an inductance (choke) in series with the discharge introduces a lagging power factor into the circuit, the combined power factor of the tube and choke being about 0.5. Using a suitable capacitor, connected across the supply mains (and not across the tube itself), the power factor of the circuit can be raised to 0.9 but by the use of the "twin tube" circuit described in Section (7) practically unity PF can be achieved.

Values of capacitors for both parallel and series correction are discussed in Section (11). Table 5 shows the approximate mains currents for various tubes and circuit arrangements.

(4.5) *The Effect of Mains Voltage Variation*

When a metal filament lamp is operated at more than the designed voltage both the total light emitted and the wattage consumed increases, though at the expense of life. As the light emitted by the lamp increases at a greater rate than the wattage the efficiency in lumens per watt also increases.

With the fluorescent tube, however, an increase in the mains voltage results in an increase in total lumens and in wattage consumed, but as the wattage increases at a greater rate than the light output, the efficiency in lumens per watt actually decreases because at the higher current density the short-wave ultra-violet radiation (2537 Å) is produced less efficiently.

The light "regulation" of the fluorescent tube with varying mains voltage is considerably better than that of a metal filament lamp. With the latter, a 1 per cent. change in mains voltage results in about a 3½ per cent. change in light output. In the fluoresecent tube, however, a 1 per cent. change in mains voltage only results in approximately a 1 per cent. change in light output (see Fig. 8).

The general effect of under-volting is decreased light output and, if severe, uncertain starting. Considerable underrunning will also reduce the life since the reduced current is not then sufficient to maintain the electrodes at their designed operating temperature. The effect of over-volting is, of course, to overload the tube and its auxiliary equipment. Clearly, therefore, to ensure correct and satisfactory

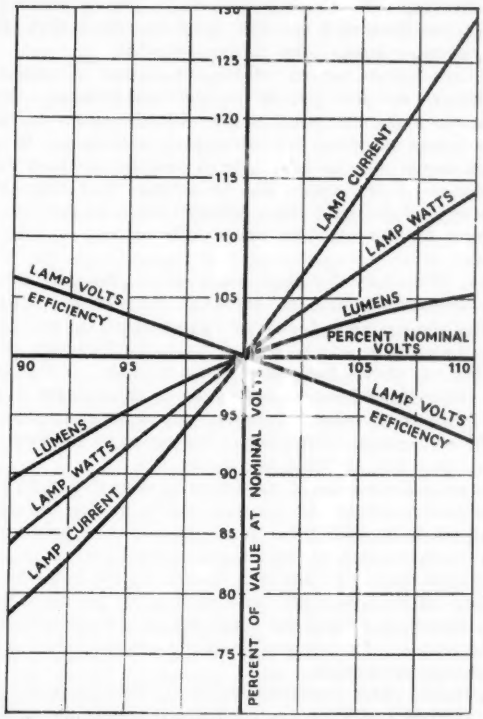


Fig. 8. Variation of tube characteristics with applied voltage.

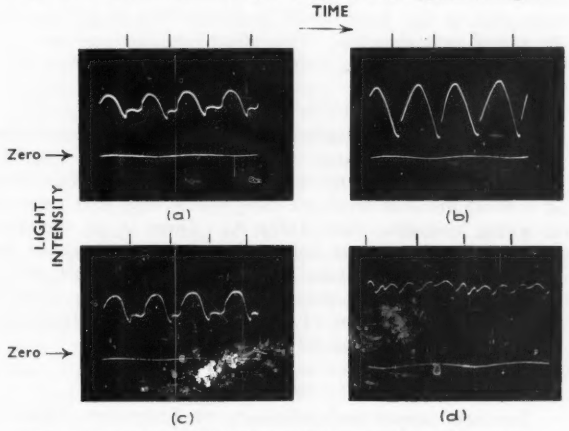


Fig. 9. Variation in light intensity during a cycle of alternating current. (Marked time interval—1/100 second.)

operation of the tube, the auxiliary equipment must be suited to the particular mains voltage concerned.

Unlike filament lamps, there is no well established relationship between mains voltage and life with fluorescent tubes, but as a rough guide it can be assumed that an increase in mains voltage of 6 per cent. will reduce the life by about 15 per cent., and conversely a reduction of 6 per cent. in mains voltage will increase the life by some 15 per cent., provided, of course, that this reduction does not affect the satisfactory starting of the tube.

(4.6) *Stroboscopic Effect*

All discharge lamps operating in conventional circuits and on alternating current have a non-uniform light output as the light drops almost to zero with each half-cycle, thus causing a periodic flicker, which is more noticeable at lower frequencies. The periodicity of this flicker will, of course.

be double that of the supply frequency The persistence of glow of the fluorescent powder helps to reduce this effect, which, in most installations is imperceptible.

In installations where rotating machinery is employed, this flicker can give rise to peculiar stroboscopic effects, such as to make the machine gear wheels appear to rotate at the wrong speed or even to appear stationary. In such installations it may be advisable to operate tubes on different phases of the supply and to arrange that there is an "overlap" of the light from different tubes so that the illumination on the machine never falls to zero at any one instant.

Fig. 9b shows the light wave form obtained when a single fluorescent tube is operated inductively. Fig. 9a shows the wave form for two tubes operated on two phases of a three-phase supply with a phase displacement of 120 deg. Fig. 9d shows the variation in intensity of the mixed light from three tubes operated on a three-phase supply. It is, however, possible to simulate the wave form shown in Fig. 9c on a single phase supply by means of the twin tube circuit described in detail in Section (7).

In general the ratio of maximum to minimum light intensity is greater in tubes of "cooler" colour so that the stroboscopic effect of such tubes is somewhat more pronounced.

A further form of flicker can sometimes be observed at the ends of a tube which is caused by the cathode glow forming on the electrode once each cycle giving a flicker at the tube-ends of half the frequency of the normal stroboscopic flicker. This flicker is usually obscured by covering up the ends of the tube.

A flicker effect sometimes occurs in which the discharge takes the place of a narrow cord which spirals and oscillates against the sides of the tube. This is due to the presence of impurities in the tube which generally "clean-up" during the initial ageing period. This effect can, however, be produced by "cold-starting" of the electrodes. (See Part 2).

(4.7) *Ultra-violet Radiation*

The ultra-violet radiation emitted by the fluorescent tube falls in the harmless range of wavelengths 4,000 to 3,000 Å; the amount of ultra-violet energy received on a surface even at a short distance from the tube is less than that received in winter sunlight. (See Table 6.) There is no radiation whatever in the danger zone below 2,800 Å, because the glass envelope of the tube absorbs the very short wavelengths. Most of the ultra-violet energy in the tube is transformed to radiation of a longer (visible) wavelength by the action of the fluorescent powder.

(4.8) *The Effect of Surrounding Air Temperature*

The light output and efficiency of fluorescent tubes is mainly determined by the generation of short-wave ultra-violet radiation set up by an electric discharge through mercury vapour at very low pressure. The quantity of this radiation is influenced by the mercury vapour pressure inside the tube (Fig. 10), which, in turn, is influenced by the air temperature in which the tube is operated. Most fluorescent tubes are designed to give their rated light output when the tube wall temperature is about 50 deg. C., which corresponds to a surrounding air temperature of about 25 deg. C. Fig. 11 shows the relationship between luminous efficiency and ambient temperature for a typical 5-ft. 80-watt tube.

In general tubes operating at a higher current density, such as a 5-ft. 80-watt tube, are somewhat less affected from the point of view of light output than tubes such as the 4-ft. 40-watt or 2-ft. 20-watt types which operate at a relatively lower current density. The relationship shown in Fig. 11 refers to a tube operating in still air; under draught conditions the effect on light output is more marked as shown in Fig. 12.

Table 6

UV radiation from fluorescent tubes
Approximate values of actual energy in milliwatts per cm²

Description of Radiation	Wavelength Region (Å)	Noon Sunlight 42 deg. N		1 metre from typical 80-watt fluorescent tube
		Summer	Winter	
Near UV (harmless)	4,000–3,250	3.5	0.5	less than 0.005
Erythemal	3,250–2,800	0.2	0.01	less than 0.0005
Harmful short-wave UV	Below 2,800	None	None	None

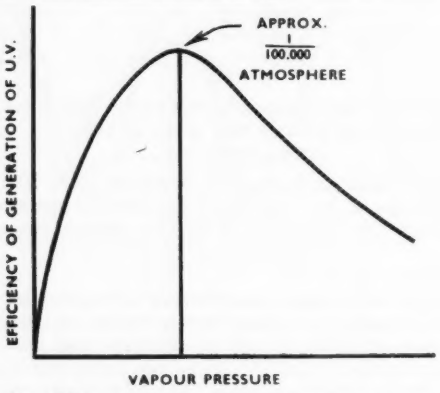


Fig. 10. Effect of variation of mercury vapour pressure on the efficiency of ultra-violet radiation generation.

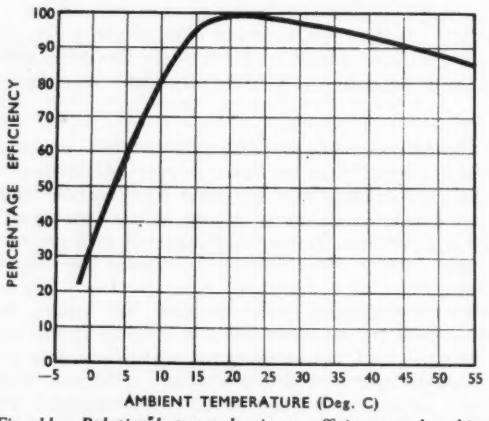


Fig. 11. Relation between luminous efficiency and ambient temperature for a typical 5-ft. 80-watt tube.

From Fig. 11 it will be noted that the luminous efficiency rises to 100 per cent. of the optimum up to about 20-25 deg. C. and then gradually falls, but at a slower rate, at higher temperatures. As the efficiency at freezing point will only be about 60 per cent. of the optimum values, totally enclosed fittings are recommended for cold situations when the tube temperature will then stabilise at a higher value. In a suitably designed fitting the light output of the tube should be up to the optimum in less than 10 minutes and up to 70 per cent. of the optimum in about four minutes even when the external ambient air temperature is down to freezing point.

Apart from its effect on the light output of a fluorescent

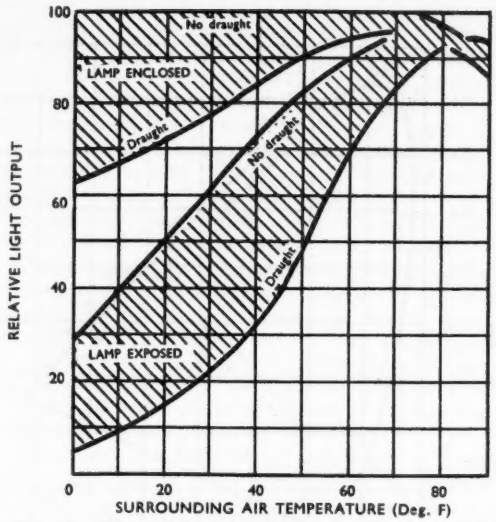


Fig. 12. Effect of draught conditions on light input of 2-ft. 20-watt tube. Shaded areas show probable range of operating efficiencies.

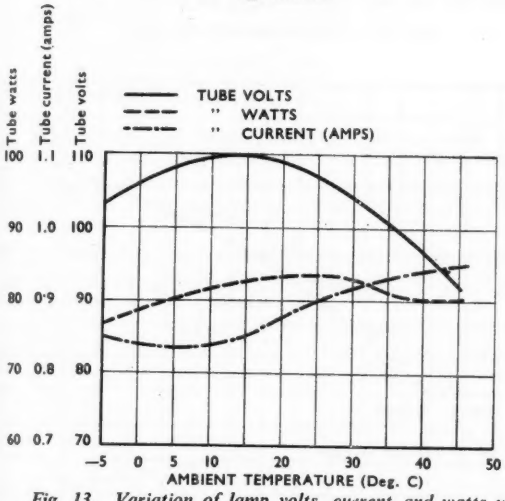


Fig. 13. Variation of lamp volts, current and watts with ambient temperature.

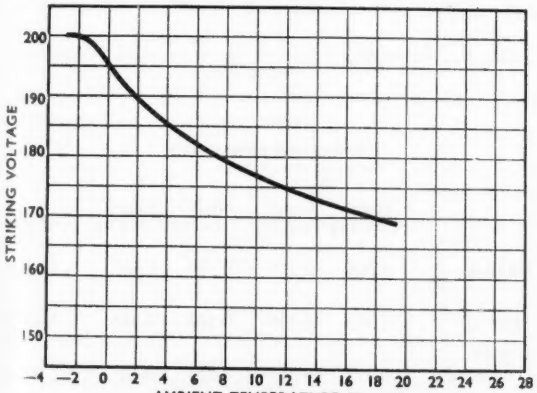


Fig. 14. Variation of starting voltage with ambient temperature of 80-watt fluorescent tube in free air.

tube the ambient temperature also influences the electrical characteristics, wattage, starting voltage, etc., and in turn the performance of tubes and their associated control gear.

Fig. 13 shows the effect of temperature on tube volts, watts and current. It will be noted that the temperature, whilst not affecting the tube watts to any material degree, has a considerable influence on tube current. At an ambient temperature of 40-45 deg. C. the tube current has increased by about 12 per cent., which will tend to reduce the effective life of the tube and possibly overheat the tube control gear. This particular characteristic must be borne in mind in the design of totally enclosed fittings where the proximity of tubes and control gear can result in a considerable rise in current.

It will also be noted that the voltage across the tube rises with temperature. This may result in reclosure of the glow switch, if the tube is used in a conventional starter-switch circuit, causing "blinking" and other undesirable effects.

The striking voltage of the tube is also sensitive to ambient temperature and rises about one volt for each one degree fall in temperature, as indicated in Fig. 14, which shows the striking voltage-temperature relationship for a typical 5-ft. 80-watt tube. From a consideration of this curve it will be seen that where the mains voltage falls to 200 volts at a time when the ambient temperature is at freezing point this particular tube will just start.

Difficulty in starting at low temperatures may cause repeated flashing of the tube with consequent deterioration of the electrodes. It is recommended that where low temperatures are likely to be experienced the capacitive (leading) circuit in conjunction with a thermal-type starter switch should be used. This arrangement should give adequate safety in starting down to an air temperature of about −15 deg. C.

(5) Colour of Fluorescent Tubes

A wide range of near-white and coloured fluorescent tubes is available. This section describes the accepted methods of specifying the colour appearance, the colour rendering properties of fluorescent tubes and the application of tube colours to various lighting tasks.

(5.1) *Colour Appearance of Fluorescent Tubes*

The process of obtaining any desired colour by the additive colour mixing of varying proportions of red, green and blue light (the three primary colours) on a white screen is well known. The CIE (Commission Internationale de l'Eclairage) system of specifying the colour appearance of light sources is based on the principles of additive colour mixing. Instead of using the three primary colours red, green and blue the CIE system employs three imaginary specified primaries X, Y and Z in order that all real colours, including spectral colours, may be embraced.

The colour appearance of a light source can be matched by a mixture of the primaries X, Y and Z and the proportions of X, Y and Z required may be said to specify the colour. Any colour may be expressed in the form of $xX + yY + zZ$ and if $x + y + z = 1$ it is only necessary in practice to quote two of the proportions, conventionally x and y.

If a diagram be plotted with the vertical axis x and the horizontal y all real colours will be in a horseshoe area as shown in Fig 15. It will be observed that the point whose co-ordinates are $x = 0$, $y = 0$ represents the "colour" Z, that whose co-ordinates are $x = 1$, $y = 0$ the "colour" X, and that whose co-ordinates are $x = 0$, $y = 1$ the "colour" Y.

The colour appearances of a number of fluorescent tubes are shown on an enlargement of the near-white region of the CIE chromaticity diagram in Fig. 16. It will be seen from Fig. 16 that the chromaticity of most fluorescent tubes used for general lighting purposes lies on or near the black

body locus and it is common to refer to the colour appearance of tubes by their colour temperature, although strictly this is inadmissible.

The following colour temperatures may be assigned to tubes:—

Northlight or Colour Matching	6,500 deg. K
Cool White de luxe or Natural	4,200 deg. K
Cool White or Daylight	4,500 deg. K
White	3,500 deg. K
Warm White	2,900 deg. K
Deluxe Warm White	2,800 deg. K

(5.2) *Colour Rendering of Fluorescent Tubes*

The colour rendering properties of a light source depend on its spectral energy or spectral luminance distribution—the latter being an energy distribution weighted by the relative eye sensitivity at various wavelengths. To simplify measurement the CIE has adopted a system in which the visible region of the spectrum is split into eight wavelength bands and the percentage of the total energy or luminance in each band is quoted.

The eight bands adopted by the CIE are:—

(1) 3,800 - 4,200 Å Far Violet
(2) 4,200 - 4,400 Å Violet
(3) 4,400 - 4,600 Å Blue
(4) 4,600 - 5,100 Å Blue Green
(5) 5,100 - 5,600 Å Green
(6) 5,600 - 6,100 Å Yellow
(7) 6,100 - 6,600 Å Light Red
(8) 6,600 - 7,600 Å Dark Red

Approximate percentage luminance distributions for a number of standard fluorescent tubes are shown in Table 7(b), together with luminance distribution for an incandescent filament and a black body radiator.

Fluorescent tubes inherently tend to be deficient in radiation in the dark red 6,600 - 7,600 Å band. To increase the percentage energy radiated in this band, however, results in a reduction in efficiency, all other things being equal, due to the lower relative luminous efficiency of energy in these wavelengths.

It cannot be overstressed that the colour rendering properties of fluorescent tubes cannot be judged by the tube colour appearance but only by consideration of the spectral band data.

(5.3) *The Application of Colours*

The visible radiation from a fluorescent tube is a combination of the continuous radiation provided by the activated phosphor and the discontinuous spectra from the mercury discharge itself. For this reason, therefore, the objective appearance of white or near-white tubes and the colour rendering provided by them is never quite identical with that of the tungsten lamp although a fairly close similarity can be reproduced. Further, whilst the colour appearance of two tubes may be much the same the colour rendering may be quite widely dissimilar; conversely the colour rendering of two tubes may be similar but their colour appearance may be quite different.

Six white or near-white colours are fairly widely manu-

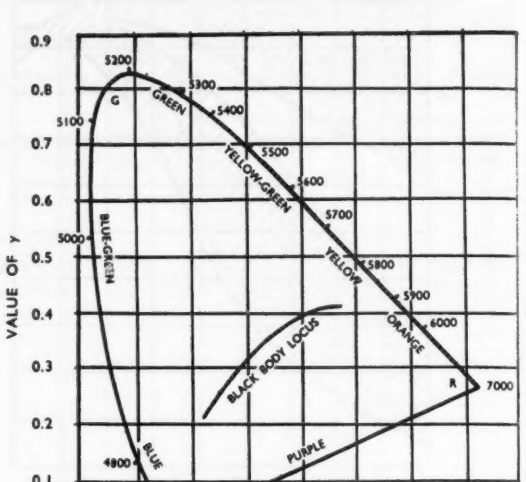


Fig. 15. CIE chromaticity diagram.

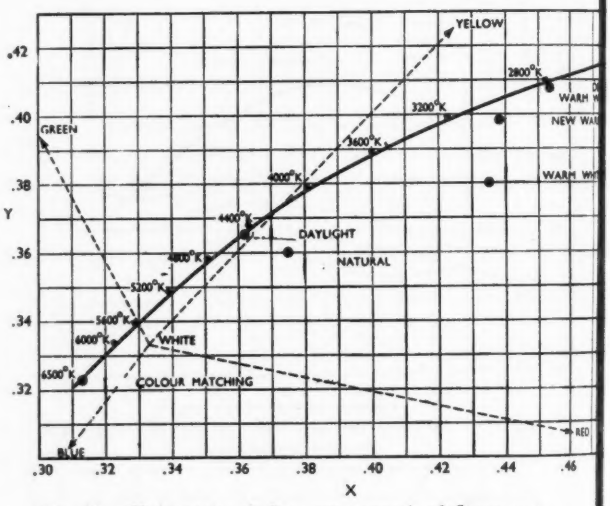


Fig. 16. Chromaticity (colour appearance) of fluorescent tubes.

Table 7 (a)
Chromaticity co-ordinates

	X		Y		
	High* Loading	Low† Loading	High* Loading	Low† Loading	Tolerance
Daylight	0.368	0.371	0.369	0.367	± 5 MPCD
Natural	0.375	0.379	0.360	0.358	± 5 MPCD
Colour Matching	0.313	0.313	0.323	0.323	± 5 MPCD
Warm White	0.440	0.446	0.400	0.398	± 7 MPCD
White	0.405	0.410	0.391	0.389	± 5 MPCD

* 80w., 30w., 2 ft., 40w. † 20w., 4 ft., 40w.

factured in this country varying from a very "cold" to a very "warm" appearance. There are Deluxe Warm White, Warm White, White, Natural, Daylight, and Colour Matching, providing a range which should satisfy most practical lighting requirements.

Four "coloured" tubes, red, green, yellow and blue, are also available in 5-ft. 80-watt rating. The red and yellow tubes incorporate an internally applied pigment as a filter which provides an extremely saturated colour with some inevitable reduction in efficiency.

It is not generally realised that the objective appearance of tubes of the same specified colour varies somewhat according to the wattage loading at which the tube is operated. A 4-ft. 40-watt daylight tube which operates at 10 watts per foot length appears slightly warmer in appearance than a 5-ft. 80-watt tube operating normally at 16 watts per foot. For this reason it may not be wise to mix lamps of different ratings in close juxtaposition.

There are, inevitably, small differences in appearance between tubes of the same objective colour, but nowadays the tolerances in manufacture are so small that practical difficulties of this nature are seldom encountered.

During the normal life of a tube some very small change in colour appearance takes place but is not generally appreciable.

(5.4) *The Choice of Colour*

The choice of colour of a fluorescent tube for any particular application requires consideration of a number of factors, e.g., the type of work, style and colour of decoration, level of illumination and the psychological effect on the individual.

Broadly speaking, the six white colours enumerated in the previous section may be divided into two categories for application purposes: Daylight, Warm White, White and Natural for general purpose lighting, and Colour Matching and Deluxe Warm White for special effect lighting. The Daylight tube is probably the most widely used colour for industrial lighting, combining a high efficiency with a psychologically stimulating effect.

The Warm White and White tubes, however, which have the highest efficiency, are being increasingly used for industrial and office lighting. Their colour appearance is also such that they blend well with tungsten filament lighting.

For shops and stores lighting the Natural tube has a wide appeal. This tube has an objective appearance between the very "cool" and "warm" tubes and has very good colour-rendering properties. Achievement of these properties inevitably results in a somewhat lower efficiency, about 20 per cent. below that of the Daylight tube.

The Deluxe Warm White and Colour Matching tubes are special service types with wide applications. The colour rendering of the Colour Matching tube closely simulates north sky daylight and is extremely consistent throughout the life of the tube—more consistent than natural daylight which varies with time and season. At relatively low levels of illumination the "colder" fluorescent tubes have a depressing psychological effect. The luminous efficiency of the Colour Matching tube is some 25 per cent. below that of the Daylight type.

The Deluxe Warm White tube was designed primarily for social and domestic use and to simulate filament lighting with which it mixes very well. The colour rendering of food, clothing and flesh is almost identical with that produced by filament lamps, making it extremely suitable for use in restaurants and recreational premises. The efficiency of the Deluxe Warm White tube is some 25 per cent. below that of the Daylight.

Colour rendering intermediate between the various types of tubes mentioned above, can, of course, be obtained by mixing the light from tubes of different colours; in general this is undesirable on aesthetic grounds and very rarely necessary.

The four "coloured" fluorescent tubes are generally used for floodlighting and decorative effects; in addition the Blue tube has found many applications in photographic printing. The efficiency of these coloured tubes is much higher than that obtained by a combination of filament lamps and coloured filters.

Table 7 (b)

Spectral luminance of fluorescent tubes
Approximate percentage luminance in spectral bands

Spectral band		1	2	3	4	5	6	7	8
Wavelength (μ)		.38—.42	.42—.44	.44—.46	.46—.51	.51—.56	.56—.61	.61—.66	.66—.76
Fluorescent Tubes—Type MCF.—	Daylight	0.01	0.30	0.30	5.0	41.0	50.0	7.0	0.13
	Natural	0.01	0.30	0.30	5.0	39.0	51.0	8.5	0.2
	Colour-Matching	0.17	0.42	0.56	8.1	45.8	39.0	8.0	0.22
	Warm White	0.005	0.22	0.10	1.7	33.0	59.6	8.9	0.15
	Deluxe Warm White	0.008	0.27	0.05	2.3	36.7	44.2	16.0	0.48
	White	0.008	0.25	0.20	3.0	36.0	55.5	8.4	0.13
	Red	—	—	—	—	1.0	20.5	73.1	5.4
	Blue	0.13	1.5	2.3	17.8	57.9	18.6	1.76	0.02
	Green	0.005	0.17	0.03	5.2	79.0	13.9	0.65	0.02
	Yellow	—	—	—	0.1	22.1	63.5	14.0	0.43
Incandescent Filament	2800 deg. K	0.006	0.06	0.25	5.3	33.5	42.7	16.6	1.54
Black Body	4800 deg. K	0.021	0.18	0.60	9.0	39.8	38.0	11.5	0.86
	6500 deg. K	0.032	0.26	0.83	10.6	41.8	35.8	9.9	0.68

PART 2: CIRCUITS

The optimum performance of a hot cathode fluorescent tube is dependent on a number of factors associated with the correct starting and running conditions. The current through the tube is, on alternating current, generally controlled by an inductance or a capacitance in series with it, or less frequently by a resistance which may take the form of a filament lamp. This series impedance is always necessary on account of the "negative resistance" of the discharge path.

On direct current a series resistance must be used, but such a resistance inevitably absorbs an appreciable amount of power. On AC, however, inductive control provides the necessary current limitation with a relatively small power loss.

If a fluorescent tube is started with the electrodes cold (assuming the necessary starting voltage is available), accelerated dissipation of the electrode coating occurs, resulting in premature end blackening and a shorter effective life. The majority of circuits used with fluorescent tubes provide some degree of cathode preheating but "cold" starting is, occasionally, employed principally on account of simplicity of the associated control gear.

Circuits for the control of fluorescent tubes can be divided broadly into two classifications, switch start circuits and starterless circuits. Starterless circuits are known and referred to in various ways, instant start, rapid start, quick start and so on; no standard nomenclature appears to exist.

In switch start circuits the inductive property of the choke is utilised to provide, in combination with some form of automatic switch, the necessary voltage surge for starting. In starterless circuits, favourable starting conditions are generally provided by a slight step-up in voltage in combination with an applied potential difference between the tube electrodes and some point, external to the tube, or alternatively by a switching pulse. "Cold" starting circuits may utilise a special fluorescent tube having an internal stripe.

(6) Switch Start Circuits

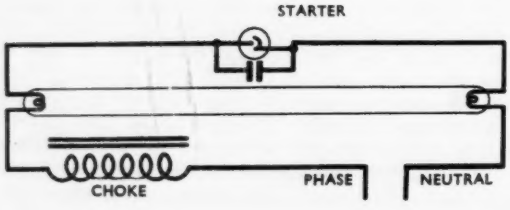
The essential components of the commonplace switch start circuit comprise the tube choke and starting switch. In addition, there are generally two capacitors, one connected across the tube for the suppression of possible radio interference, and one connected across the mains for power factor correction.

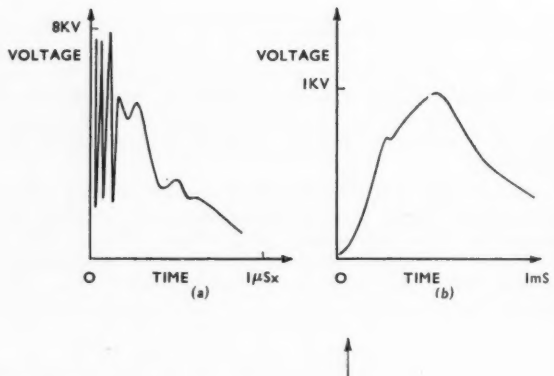
Two types of starter switch are in popular use in this country, the glow switch which is a voltage-operated device and the thermal switch which is current-operated.

Fig. 17 shows a common form of glow starter. This consists of a small discharge tube of the negative glow type, filled with a mixture of helium and hydrogen gas and in which the electrodes form the switch contacts. One electrode is fixed and the other carries a U-shaped bi-metallic strip which flexes when heated and is fitted with a suitable contact at its free end. This is known as the "asymmetric" type of switch, but other types of switch having two symmetrically arranged bi-metals are also in general use. The switch, together with its associated interference suppression capacitor, is normally contained in the metal canister also illustrated. This canister may have two or four electrical contacts (manufacturing practice differs in this respect). In the case of the four contact starter, it will be found that one

Fig. 17. (left) Typical glow starter switch.

Fig. 18. (below) Simple choke controlled glow switch circuit.





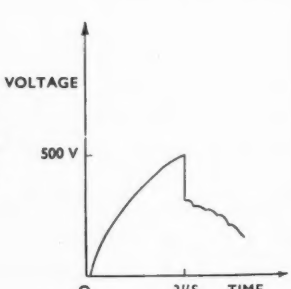


Fig. 19. Oscillograms of typical transient voltage waveforms across starter contacts. (a) no parallel condenser, (b) parallel condenser—bimetal positive, (c) parallel condenser—bimetal negative.

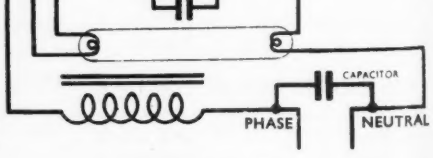


Fig. 20a. (left) Thermal starter switch.

Fig. 20b. (right) Thermal starter circuit.

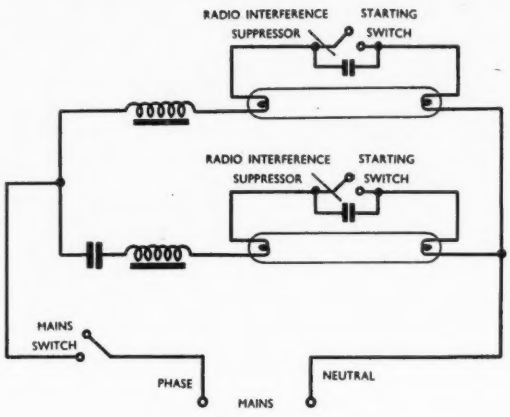


Fig. 21. Twin tube circuit.

After the tube discharge has started, the voltage across it will be about half the mains voltage, the remainder being taken up by the choke. This voltage is insufficient to start a discharge in the glow switch which remains effectively out of operation until the tube has to be restarted.

The glow switch starter is generally recommended for use with 5 ft. 80-watt, 4 ft. 40-watt and 3 ft. 30-watt tubes on AC supplies of 200-250 volts.

The thermal or current operated switch which is shown in Fig. 20a comprises one or more bi-metallic strips in close juxtaposition to a small low-resistance heater coil. The construction should, in a properly designed switch, compensate for changes in the external ambient temperature. The elements of the switch may be in free air or may be enclosed in a hydrogen-filled glass bulb for arc quenching; the complete device including the suppressor capacitor is contained in a metal or plastic canister with four contact pins. Two of these pins are larger than the other pair, the large pins being connected to the switch contacts and the small pins

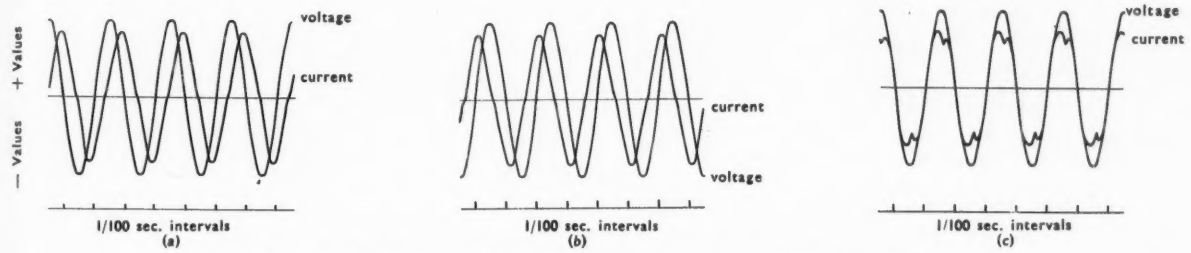


Fig. 22. Oscillograms showing voltage current waveforms of twin lamp circuit.

pair of contacts is much smaller in diameter than the other pair, the switch contacts being connected to the former.

The operation of the switch is best understood by studying it in relation to the simple choke-controlled tube circuit shown in Fig. 18. The cycle of operations is as follows :—

(a) When the switch S.1. is closed, practically full mains voltage is applied across the tube and across the glow switch which is connected in parallel with it. The mains voltage is generally insufficient to start the main discharge in the tube, but the discharge in the glow switch heats the bi-metallic strip which bends and makes the contact.

(b) The glow switch contacts having closed, the circuit is completed through the choke and two tube electrodes in series and the current through the electrodes heats them to incandescence and causes ionisation of the gas in their immediate vicinity. The current through the electrodes is suitably limited by the choke coil.

(c) As the glow switch is now short-circuited (the switch contacts being closed) there is no longer any heat from the glow discharge in the switch, and the bi-metallic strip cools down causing the switch contacts to open, within a second or two. Breaking the circuit produces a high voltage surge (caused by the collapse of the magnetic field in the choke) of up to 800/1,000 volts which is generally sufficient to strike the discharge in the tube. Should the tube fail to strike at the first opening of the starter contacts, a discharge will pass again and the cycle of operations will be repeated until the tube starts.

Oscillograms of typical transient voltage waveforms measured across the starter switch contacts are shown in Fig. 19. Fig. 19a shows the transient when no parallel capacitor is used and Fig. 19b with the normal suppression capacitor. In the latter case the peak voltage is reduced but the pulse-voltage area is increased so that more energy is available for starting.

being connected to the heater coil. The simple thermal switch circuit is shown in Fig. 20b.

The switch contacts of the thermal type switch, unlike those in the glow starter, are closed in the "off" position so that when the tube is switched on current immediately flows through the tube electrodes and through the heater coil of the starter. After a second or so the heat from this coil causes the bi-metallic strips to bend and break contact and the inductive surge from the choke starts the discharge in the tube. The heat from the coil keeps the starter contacts open all the time the tube is in operation but immediately it is switched off the bi-metal cools and the contacts reclose ready for the next start.

The characteristics of the thermal switch must be such that the contacts will not reclose under the tube "running" condition during which the tube running current will generally be lower than the starting current. The thermal switch circuit is applicable to all ratings of fluorescent tubes operated singly or in series as described later, but as different ratings of thermal switch are manufactured, the correct combination of tube and switch must be used.

The power factor of the simple inductive circuit described above is about 0.6 which may be corrected to 0.85 or so by the use of a suitable capacitor as described in Section (16).

Special twin glow starters for operating two short tubes in series are also available.

(7) The Twin Tube Circuit

When tubes are operated in pairs or in multi-lamp fittings, the "twin tube" circuit may be used to advantage. In this circuit one tube is operated in series with a choke and the other in series with a choke and a capacitor as shown in Fig. 21. The circuit with the choke alone in series has a power factor about 60 deg. lagging and that with the choke

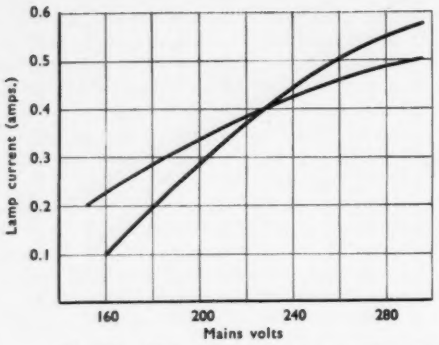


Fig. 23. Mains volts—lamp current curves in lead-lag circuits.

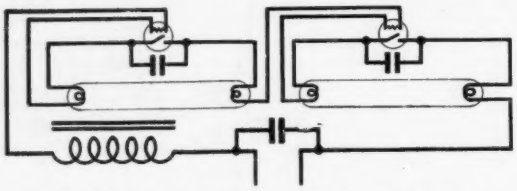


Fig. 24. Series circuit for short fluorescent tubes.

and series capacitor a power factor of some 60 deg. leading. The resultant power factor of the combined circuits is approximately unity.

Figs. 22a and b show the manner in which the mains voltage and tube current for inductively and capacitively controlled tubes vary throughout a cycle and Fig. 22c shows the mains voltage and combined current for the twin tube circuit.

As the light from each tube is in phase with the current in the tube, and the current in one tube is 120 degrees out of phase with the current in the other, the light from the two tubes will also be 120 degrees out of phase. This results in a considerable "smoothing out" of the light-time cycle as shown in Fig. 9c. A further major advantage of the capacitive circuit is that with varying mains voltage a much smaller variation in tube current occurs than in the purely inductive circuit. (Fig. 23.) This means that tubes operated capacitively will continue to operate even when the mains voltage falls to quite a low value. The use of the twin tube circuit also enables a saving of one capacitor for every pair of circuits compared with circuits where parallel correction is employed.

(8) Series Operation

It has been mentioned previously that the relatively low tube voltage of the 24-inch and 18-inch tubes renders them suitable for series operation on 200/250 volt supplies from a single set of control gear. The circuit for two such tubes is shown in Fig 24. A starter switch is required for each tube, the thermal type being recommended as glow starters are generally unsuitable for operation on voltages materially below 200 and only about half of this voltage is available across each tube when two are operated in series. The current rating of the thermal switches must, of course, be suited to the current rating of the tubes concerned. In multi-tube fittings employing multiples of four short tubes, a twin tube arrangement such as shown in Fig. 25 may be used.

(9) Starterless Circuits

(9.1) *Standard Transformer Heating (Inductive Circuits)*

The majority of so-called "starterless" circuits provide electrode pre-heating by means of a small auto-transformer. This transformer, apart from providing electrode heating, can be arranged to step-up, for starting purposes, the voltage across the tube, but the usual series choke is still required for stabilising purposes.

Typical circuits of this type are shown in Figs. 26 and 27. In Fig. 26 the choke is connected between the mains and the transformer, this class of circuit being known as "compensated" as once the tube strikes the voltage across the transformer falls and the electrode heating current is reduced. The temperature of the electrode is then chiefly maintained by the normal tube current.

In the uncompensated type of circuit shown in Fig. 27, the electrode heating transformer is connected directly across the mains, and once the tube strikes no reduction in circulating electrode current results. Obviously, if the transformer were designed to provide the full starting current to the electrodes, these electrodes would, once the tube had started, be overloaded as they would then be carrying a high circulating current in addition to the normal arc current.

Some tubes, e.g., the 4-ft. 40-watt and 3-ft. 30-watt, will start with comparatively low electrode heating and in these cases the starting transformer can be designed in such a way that, even after the tube has struck the combined electrode, circulating and tube currents will not be sufficiently great as to affect the reliable performance of the tube.

Mention has already been made of the absence, in many "starterless" circuits, of any form of voltage surge usually necessary for starting the tube. Starting has, therefore, to

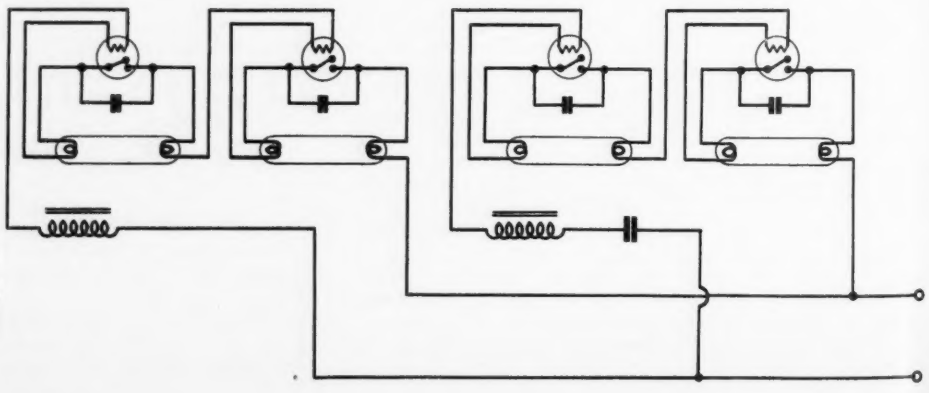


Fig. 25. Multi-tube circuit.

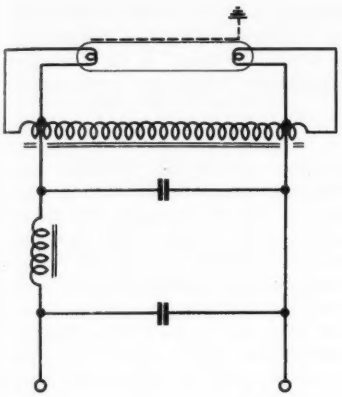


Fig. 26. Preheat starterless inductive compensated circuit.

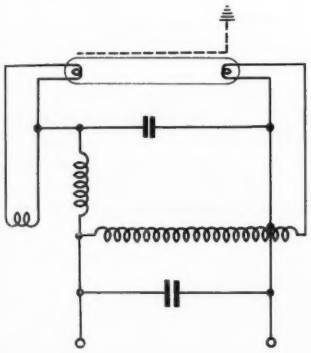


Fig. 27. Preheat starterless inductive uncompensated circuit.

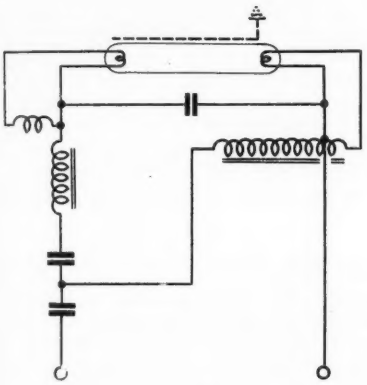
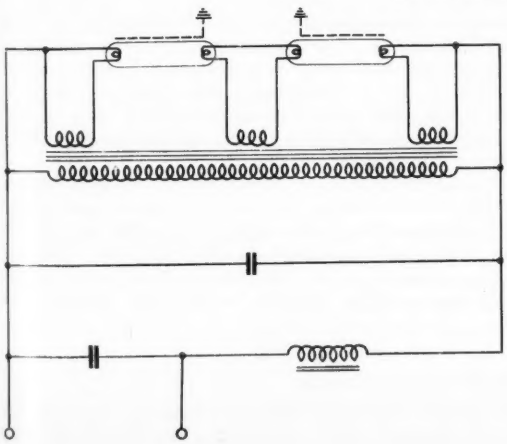


Fig. 28. Preheat starterless compensated capacitive circuit.

Fig. 29. (below) Instant-start circuit for two short lamps.



be facilitated in some different way, one common method being to provide a " proximity " earth. This may be done by having a metal or metallised stripe running along the outside wall of the tube and soldered to the caps which can then be electrically bonded, through a metal lampholder or other convenient means, to the earthed fitting. On switching, a potential difference approximating to the mains voltage on a normal supply system is applied between the electrodes and the outside stripe which, in conjunction with the pre-heated electrodes, is generally sufficient to " trigger " the tube.

The successful operation of fluorescent tubes in normal starterless circuits is mainly dependent on two factors: (1) an adequate potential difference between the unearthed electrode and the adjacent portions of the tube wall, and (2) the tube surface must be substantially equipotential. If this latter condition does not exist a potential " barrier " can be set up which prevents the discharge from spreading down the tube. In the case of tubes not fitted with an external metal stripe, and operated under conditions of even normal humidity, the moisture film deposited on the tube strongly influences the potential gradient along the tube wall and inhibits starting. Deposition of this moisture film can be avoided by coating the tube with a thin transparent layer of silicone varnish. It is recommended that, in addition to using a siliconed tube the fitting associated with the tube should be earthed.

In assessing the relative advantages and limitations of striped and siliconed tubes, it is fairly generally agreed that the earthed stripe lamp provides the greater factor of safety under adverse conditions of mains voltage and temperature. When used in earthed metal fittings, siliconed tubes should give reliable starting down to about 8 deg. C. but the earthed stripe lamp should be satisfactory as low as 0 deg. C.

(9.2) *Standard Transformer Heating (Capacitive Circuits)*

Under normal circumstances the current through a fluorescent tube is substantially symmetrical, but towards the end of life it is not uncommon for one electrode to lose much of its emissive coating whilst the other may be fully emissive. Under these conditions the tube acts as a partial rectifier and a DC current of as much as 0.5 amps may, in the case of a 5-ft. 80-watt tube, for example, flow through the tube and the main winding of the starting transformer with possible serious effects.

The capacitive starterless circuit shown in Fig. 28 obviates the above effect and utilises a double or centre tapped series capacitor, one section of which is in series with the transformer primary and " blocks " the asymmetrical current. Capacitive circuits of this type may be used with the inductive circuits described above to obtain the advantages of " twin tube " operation.

(9.3) *Starterless Circuits for Tubes in Series*

Short fluorescent lamps may be operated in series in the circuit illustrated in Fig. 29. A single transformer with an additional secondary winding provides pre-heating for two of the electrodes connected in series.

(9.4) *Pulse Start Circuits*

Modified types of inductive starterless circuits have been introduced in which a pulse is initiated on first switching. A circuit of this type is shown in Fig. 30 in which it will be noted that the power factor correction capacitor is connected to a tapping on the choke winding. Normal transformer heating of the tube electrodes is provided. When the tube is switched on the PF capacitor is charged through part of the choke winding and as the tapped choke then acts as an auto-transformer a voltage pulse is applied across the tube for

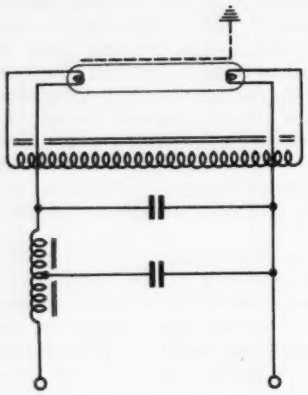


Fig. 30. Typical pulse start circuit.

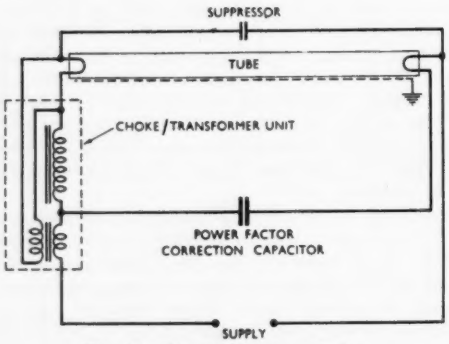


Fig. 31. Capacitive start circuit.

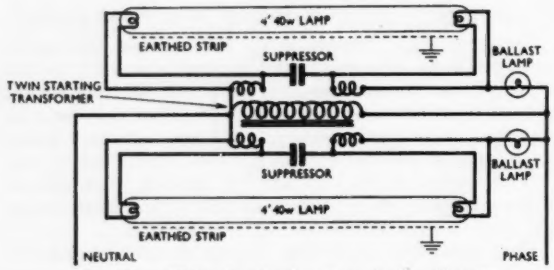


Fig. 32. TLC circuit for two 4 ft. 40-watt straight tubes.

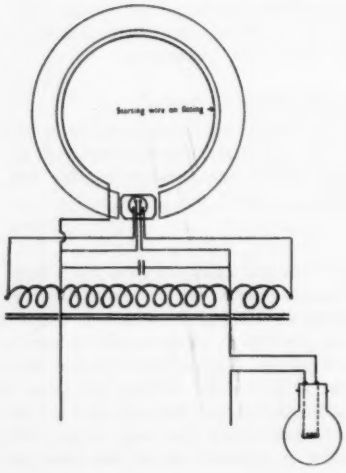


Fig. 33. TLC circuit for 40-watt circular tube.

starting purposes. Careful design of the choke is necessary to avoid serious distortion of the waveform or the application of too high a voltage across the tube. If the tube does not strike on the first switching, reswitching may be necessary.

(9.5) *Capacitive Gear*

A new type of starterless circuit has recently been introduced (Fig. 31). One electrode is heated by a small current transformer and the other through the power factor correction capacitor. Both electrodes are thus quickly brought up to emission temperature, and the voltage between them—being approximately equal to the mains voltage, allowing for a small drop across the primary of the current transformer—starts the tube. Two advantages of this circuit are the high power factor achieved (about 0.98) and the economy in construction as the current transformer may be wound on an extension of the conventional choke core.

(10) Tungsten Lamp Control

The tungsten lamp control circuit (TLC), which is suitable only for AC mains, employs a specially rated tungsten ballast lamp in series with each fluorescent tube and a small transformer for electrode heating. This arrangement enables the normal choke to be dispensed with. A suitable transformer in conjunction with an earth-striped fluorescent tube also provides instant starting and the power factor of the circuit is practically unity, so that no correction capacitor is required.

Fig. 32 shows a suitable circuit for operating two 4 ft. 40-watt instant start tubes from a single small transformer. Two tungsten ballast lamps, each taking about 65 watts, are employed, making a total consumption of about 210 watts.

The TLC circuit has also been applied to the 40-watt circular fluorescent tube with a number of features which differ from those employed with straight tubes as shown in Fig. 33. Owing to the practical difficulties of attaching a starting stripe to the curved wall of the tube, reliable starting is effected by providing an insulated conductor connected to the neutral of the supply and held in close proximity to the tube surface, and by employing a silicone water repellent coated tube.

(11) Circuits for 8 ft. 125-watt Tubes

On account of the relatively high arc voltage of the 8-ft. tube some step-up of mains voltage is necessary on most supplies. Fig. 34 shows an inductive circuit employing a step-up leakage reactance transformer which also provides electrode heating in a similar manner to the "instant start" transformer. The regulation of the transformer is such that current limitation is provided without the use of a series choke and no starter is necessary. The circuit is shown with a power factor correction capacitor which is omitted if the tube is used in conjunction with a second tube operated capacitively to obtain the advantages of the "twin tube" arrangement.

The capacitive circuit is shown in Fig. 35 and consists of a standard 80-watt choke and series capacitor and a small step-up transformer for mains voltages from 200 to 240. On 250-volt mains this transformer is unnecessary. In the capacitive circuit a thermal-type starter of the same current rating as that normally employed with a 5-ft. 80-watt tube is used.

(12) Direct Current Circuits

Hot cathode fluorescent tubes are designed primarily for use on alternating current. Such tubes can also be operated

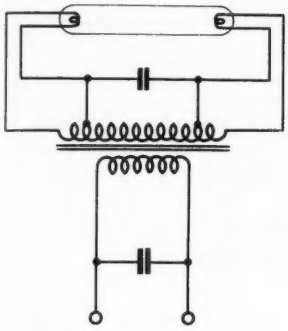


Fig. 34. Instant start circuit for 8 ft. 125-watt tube.

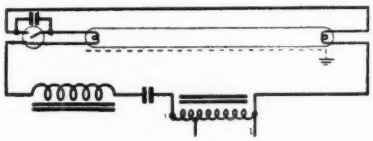


Fig. 35. Capacitive circuit for 8 ft. 125-watt tube.

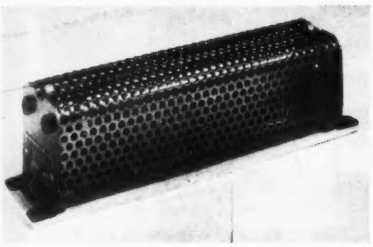


Fig. 36. Enclosed resistance for DC operation and polarity reversing switch.

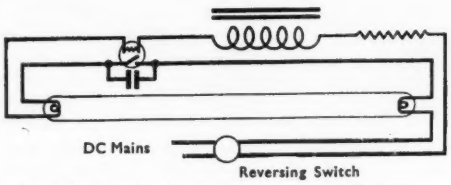


Fig. 37. Circuit for DC operation of fluorescent tubes.

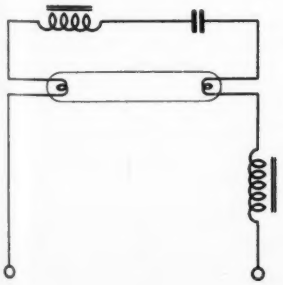


Fig. 38. Typical circuit for HF operation of fluorescent tubes.

on direct current, though by so doing certain limitations and disadvantages are incurred. Although DC operation is not as efficient as AC operation, it nevertheless offers an appreciable advantage in luminous efficiency over the tungsten filament lamp and there are many lighting applications where the advantages of the fluorescent tube more than outweigh the loss in overall efficiency resulting from the resistive stabilisation which the DC fluorescent tube circuit requires.

When fluorescent tubes are used on DC a resistor of appropriate value and rating must be connected in series with each tube. This resistor is in addition to the normal choke coil used on AC, which must be retained in order to provide the induced voltage surge necessary for starting the lamp. The recommended values of these resistors for different sizes of fluorescent tubes together with their current rating are given in Tables 13 and 14.

One of the characteristics of fluorescent tubes operated on a DC supply is the migration of ionised mercury vapour to the negative electrode with consequent darkening and loss of light at the anode end of the tube. Ambient temperature has also an effect on the speed of migration, particularly at values below 20 deg. C. This end-darkening effect is more rapidly apparent with the longer fluorescent tubes, and provision for reversing the polarity must be made. It is convenient to use a rotary on-and-off reversing switch for this purpose as reversal can take place every time the tube is switched. Common types of enclosed resistors and rotary reversing switches are shown in Fig 36.

The usual circuit for operating a single fluorescent lamp on DC is illustrated in Fig. 37. A thermal-type starter switch is recommended as most glow-type starter switches are generally asymmetric in construction and will not operate equally well with either polarity.

The period of reversal varies somewhat between tubes of different lengths and even between tubes of the same length. In general, however, the 5-ft. 80-watt tube will require reversal about every six hours, but the shorter tubes such as the 2-ft. 20-watt may operate satisfactorily up to 24 hours on the same polarity.

Starting is more difficult on DC than on AC due to the absence of the AC peak voltage and the use of 5-ft. 80-watt lamps on supplies likely to fall below 200 volts is not recommended. The 4-ft. 40-watt and shorter lamps, however, are somewhat more flexible from this point of view. Stroboscopic flicker and power factor correction problems are, of course, absent on DC.

Before much experience in the use of fluorescent tubes on DC had been gained it was thought that tube life would be lower than on AC operation. However, it would now appear that the average life is comparable with that on AC under the same operating conditions, provided polarity reversal is carried out. Some manufacturers supply special tubes for DC operation which have an increased amount of mercury in them which slows up the " migration " effect.

(13) High Frequency Operation

As the frequency of the supply used for fluorescent tubes is increased the luminous efficiency increases, being some 10 per cent. higher at 400 cycles than at 50 cycles. Other advantages of higher frequency operation are the greatly reduced weight and bulk of the control gear and the fact that a simple resonant circuit such as shown in Fig. 38 may be employed. The overall efficiency of a number of tubes operated on high frequency may, however, be less than on a 50-cycle supply due to the inevitable losses in frequency conversion. Circuits of the resonant type are not satisfactory for normal frequency supplies due to the distortion of the waveform and the bulk of the control gear required.

(14) Cold Starting Circuits

Mention has already been made of the fact that, provided a sufficiently high voltage is available, a standard fluorescent tube may be started, even when the electrodes are cold and therefore only partially emissive. Such starting, however, shortens the life of the tube and accelerates end blackening; in addition, the size and cost of the auxiliary gear to provide this high voltage is likely to be much greater than with standard pre-heat circuits.

One special type of fluorescent tube, however, has been produced which will strike "cold" satisfactorily on normal mains voltage in starterless circuits; this is the internal stripe tube shown in Fig. 39, associated with a ballast lamp similar to that used with the TLC circuit. When the tube is switched on, ionisation occurs between one electrode and the end of the internal stripe which is connected electrically to the other electrode and the tube will strike even on ordinary mains voltage. The resistance of the stripe is such that under running conditions the arc takes most of the current but there is still some wattage loss (7-10 per cent. of input) in the stripe.

The "cold" starting of the electrodes also results in some shortening of life, the life of an internally striped tube being about 50 per cent. of that of a normal tube operated in a conventional pre-heat circuit.

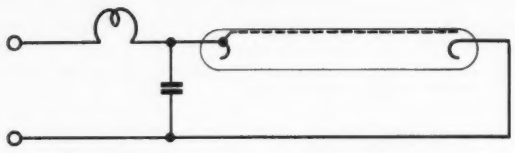


Fig. 39. Ballast circuit for internally striped tubes.

(15) Three-phase Operation

(15.1) *Neutral Currents in Three-phase System*

When fluorescent tubes are operated from a three-phase supply an appreciable current may be caused in the neutral conductor due to the harmonics inherent in the current waveform of discharge lamps. The actual harmonics concerned, being the odd multiples of three, are additive in a balanced arrangement. The ballast design will also influence these harmonics and their effect may be minimised by designing the ballast to restrict the flux density of the choke core.

The public supply may contain a small percentage of harmonics and a greater percentage may be found on a fully loaded private supply. If shunt capacitors are used for power factor correction, supply harmonics will give rise to increased current harmonics in the capacitor which will also increase the neutral current.

(15.2) *Neutral Current/Line Current Ratio*

As the line current is reduced by the power factor correction capacitor the ratio of neutral current to line current is increased. Neutral current increases with higher capacitive values of the power factor capacitor (see Table 8) and it is not, therefore, always desirable to aim for a very high overall power factor. An increase in the harmonic content of the supply will also result in an increase in neutral current. If the load is to be mainly discharge lighting, it is considered desirable that the current capacity of the neutral conductor should be similar to that of the lines. Alternators are generally designed to accept a 50 per cent. neutral current/line current ratio, and in cases where excessive neutral current is encountered it may be limited by the introduction of a three-phase interconnected star reactor between the lines and neutral of the installation.

In cases where the harmonic content of the supply is low it is generally possible to reduce the neutral current/line current ratio to an acceptable value by introducing a small choke in series with each shunt power factor capacitor. The flux density in the core of the choke must be fairly low and its impedance should be of the order of 20-25 per cent. of that of the capacitor at fundamental frequency.

Table 8
Characteristics of 3-phase circuits

Capacitance (mfd)	Overall Power Factor	Line Current (amps.)	Neutral Current (amps.)	Neutral/ Line Current Ratio (per cent.)
0	.46	.91	.17	19
8	.81	.54	.25	47
10	.91	.48	.28	57
12.5	.96	.45	.31	69

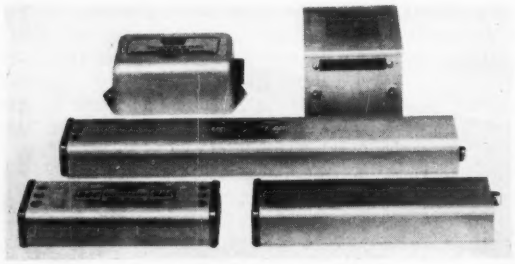


Fig. 40a. Various types of chokes.

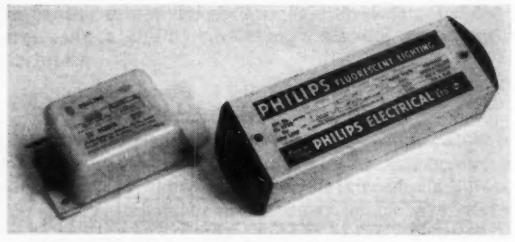


Fig. 40b. 40-watt choke of old design with (left) new 40-watt Polyester choke.

Table 9
Approximate wattage losses in chokes

Tube consumption (watts)	Overall Length (ft)	Voltage Range	Approx. Choke Consumption (watts)	Approx. Winding Resistance (ohms)
15	1½	100–250	4*	18
20	2	100–250	4*	17
30	3	200–250	8	37
40	2	100–130	7½	8
40	4	200–250	8	36
80	5	200–250	13	9
125	8	200–250	13	9

* Loss per lamp.

Table 10
Capacitors for power factor correction (parallel)

Mains Volts	Tube			Capacitor Capacity (mfd)	Approx. P.F.	Circuit
	Size		Wattage			
	(ft.)	Diam. (ins.)				
200/210	8	1½	125	20	0.9	Single
220/230	8	1½	125	15	0.9	,,
240/250	8	1½	125	15	0.95	,,
200/250	5	1½	80	7.5	0.85	,,
200/250	4	1½	40	3.25	0.85	,,
200/250	3	1	30	3.25	0.85	,,
200/250	2	1½	40	7.5	0.85	Two-in-Series
200/250	2	1½	20	3.25	0.85	,,
200/250	2	1½	20	4.5	0.85	Single
105/120	2	1½	20	5	0.85	,,
200/250	1½	1	15	3.25	0.85	Two-in-Series
200/250	1½	1	15	4.5	0.85	Single
105/120	1½	1	15	5	0.85	,,

Table 11
Series capacitors for capacitive circuits
(Mains voltage 200/250; approx. P.F.—0.5 leading)

Tube			Capacitor	Circuit
Length ft.	Diam. in.	Wattage	Capacity in MFD.	
8	1½	125	7	Single
5	1½	80	7	,,
5	1	50	2.7	,,
4	1½	40	3.25	,,
3	1	30	2.7	,,
2	1½	40	7	Two-in-Series
2	1½	20	3.25	,,
2	1½	20	2.7	Single
1½	1	15	2.7	Two-in-Series
1½	1	15	2.7	Single

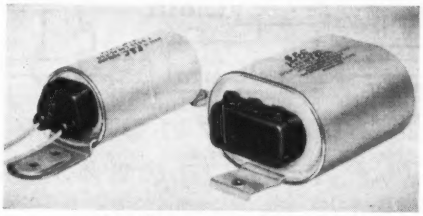


Fig. 41. Aroclor capacitors.

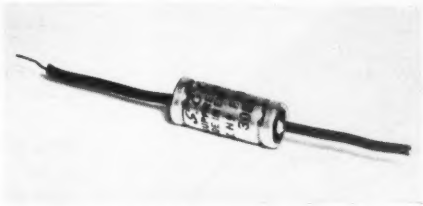


Fig. 42. Radio suppression capacitor.

(16) Control Gear for Fluorescent Tubes

(16.1) *Chokes*

A choke consists fundamentally of a coil of insulated wire wound on a laminated core, this core being provided with a small air gap which enables the magnetic characteristics to be closely controlled. In most modern designs the choke is enclosed in a metal container filled with bitumen for mechanical protection and heat dissipation. The design of a satisfactory choke involves more than the mere provision of suitable magnetic characteristics; it must be reasonably quiet in service and its temperature rise under fault conditions must be below a safe limit.

A roughly cubic shape of choke gives the lowest wattage loss and when fluorescent tubes were first introduced, chokes generally took this form and in the 80-watt size had a loss of about 10 watts. The cubic shape did not, however, lend itself to mounting in slender fittings and the "elongated" type which has about twice the loss of the cubic type, was introduced. Within the last few years a compromise between the cubic and elongated types of roughly "brick" dimensions has been developed, and is becoming the standard design. Table 9 shows typical losses for modern brick chokes of various ratings and Fig. 40a illustrates various types of chokes.

Chokes are generally manufactured in a series of fixed voltage ranges 200-210, 200-230, 230-240 and 240-250 volts, the particular rating being chosen to agree with the "average" voltage of the supply mains. "Tapped" chokes covering a wider range of supply voltages are manufactured but are inevitably more expensive than the untapped variety and unnecessary except in special circumstances.

So far as the temperature rise of chokes is concerned the upper limit of winding temperature for most types is about 130 deg. C. In practice, under normal operating conditions the internal temperature rise is of the order of 40 deg. C—a safe margin, but care must be taken when operating chokes in abnormally high ambient temperatures.

A recent introduction in Britain is the polyester type ballast employing a thermosetting resin filling which cannot melt. The size and weight of this choke (Fig. 40b) are considerably less than those of previous designs.

(16.2) *Capacitors*

The capacitors used in fluorescent tube circuits are generally of the paper interleaved type and filled with petroleum jelly. They are generally of elongated form and are of two main types, those for parallel power factor correction and those for series operation in leading circuits.

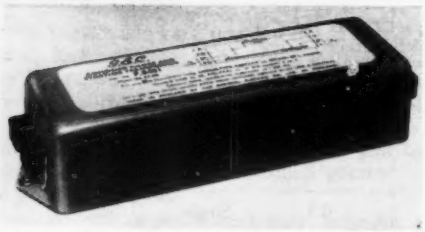


Fig. 43. Combined choke and starting transformer for 80-watt tubes.

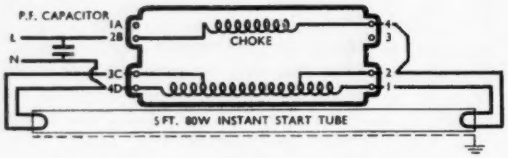


Fig. 44. Wiring of unit illustrated in Fig. 43. (Inductive).

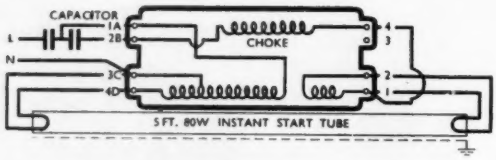


Fig. 45. Wiring of unit shown in Fig. 43. (Capacitive).

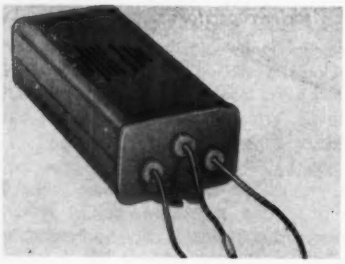


Fig. 46. Split capacitors.

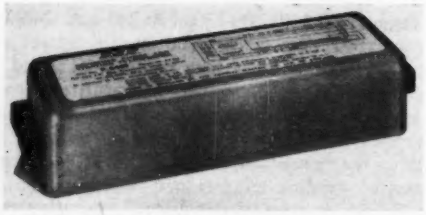


Fig. 47. Combined choke, transformer and capacitor unit for two 4 ft. 40-watt tubes on lead-lag circuit.

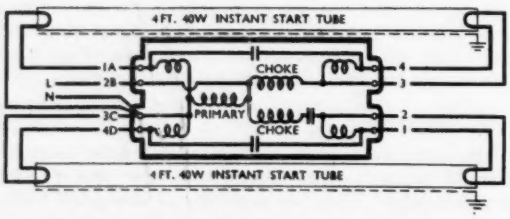


Fig. 48. Internal connections of control unit shown in Fig. 47.

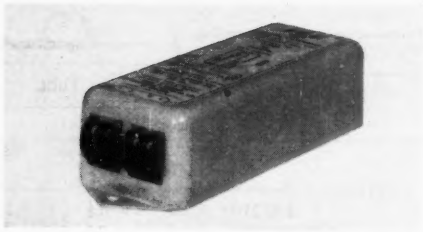


Fig. 49. Capacitor type control gear.

Capacitors for series operation are considerably larger than those used for parallel correction as the voltage developed across them in the capacitive circuit may be as high as 350 so that additional insulation must be provided. Tables 10 and 11 give the recommended values for capacitors for the various types of circuits already described. Recently, capacitors filled with "Aroclor" have been developed and may supersede the petroleum jelly type. Typical parallel and series capacitors are shown in Fig. 41.

For the suppression of radio interference in circuits not employing the conventional starter switch which incorporates a capacitor, a small additional capacitor of about 0.02 μ F capacity is connected across the tube. Such a capacitor is shown in Fig. 42.

(16.3) *Instant Start Gear*

The essential components of the normal instant start circuit are a choke and transformer which provides the requisite cathode preheating current and a suitable voltage to start the tube. Modern tendency is to combine the choke and transformer in a single unit and in some cases the capacitor may be included within the same container.

Fig. 43 shows a combined choke and starting transformer for 80-watt fluorescent tubes, whilst Figs. 44 and 45 show the internal connections for inductive and capacitive operation. The split capacitor shown in Fig. 46 is necessary in order to prevent rectification effects should the tube fail to start as described in Part 2. Fig. 47 shows a combined choke, transformer and capacitor unit for operating two 4-ft. 40-watt tubes on lead-lag circuits and Fig. 48 shows the internal connections of this unit.

The capacitive switchless start gear described in Section 9.5 is shown in Fig. 49. It is available for 5-ft. 80-watt, 4-ft. 40-watt and 3-ft. 30-watt tubes; gear for other ratings is being developed.

(16.4) *Starter Switches*

Starter switches are made in two principal types—glow and thermal. The early pattern glow switch made for the 80-watt lamp only had a standard SBC two-contact cap, and was supplied in two voltage ranges, 200/220 and 230/250. The present standard, glow or thermal, starter switch is housed in a four-contact canister (Fig. 50a) which also incorporates a radio-suppression capacitor. Incorrect fitting of the starter in its appropriate socket is prevented by making two of the diagonal cap pins and the two corresponding socket contacts of a larger size.

In the glow-type canister switch, the switch is always connected across the large contacts, the two smaller-diameter contacts being short-circuited inside the canister.

In the thermal-type canister switch the switch contacts are also connected across the large diameter contacts; the heater coil is connected across the two smaller ones. Some starter sockets have a short-circuiting device across the contacts BB, which comes into operation when the starter is withdrawn, thus maintaining the circuit and keeping the lamp alight if it is desired to remove the starter.

The standard canister ensures that, if the circuit is appropriately wired, the glow and thermal starters will be

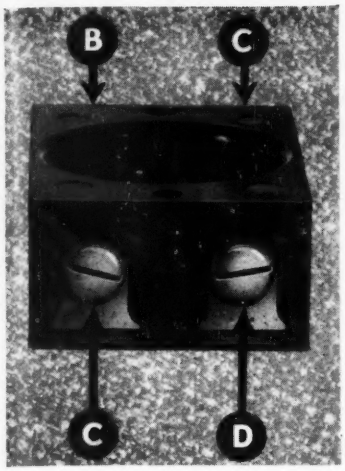


Fig. 50a. Four contact starter socket.

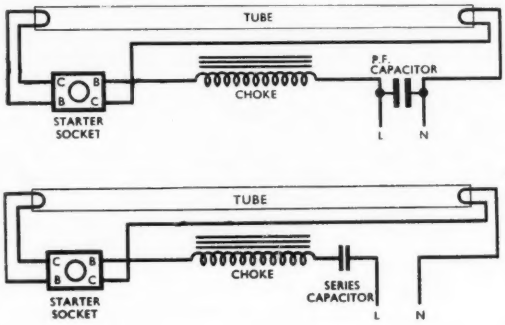


Fig. 50b. (below) Wiring of four contact starter sockets. (Top, single tube circuits; bottom, capacitor and twin tube circuits).

electrically and mechanically interchangeable; it must be remembered, however, that for certain purposes (for example, with two lamps operated in series) thermal starters must be used.

In the glow-type canister switch a single voltage range, 200/250, is generally supplied, and one type covers the 3-ft. 30-watt, 4-ft. 40-watt and 5-ft. 80-watt tubes. Several different ratings of thermal switch cover the complete range of 18-in. to 5-ft. tubes as the current rating of the thermal switch heater coil must clearly be suited to the current taken by the particular tube with which it is associated.

Table 12 gives the switch types suitable for operating the various sizes of fluorescent tubes on the different circuits already described. Fig. 50b shows the method of wiring the starter socket in the circuit.

(16.5) *Control Gear for DC Circuits*

The series used on AC has a resistance of only a few ohms and on DC mains is no longer capable of limiting the current to the designed value. If tubes are to be operated on direct current supplies a resistor of the appropriate value and current rating must be connected in series with the tube. A choke is necessary in addition to provide the inductive voltage surge to start the discharge.

The value of this resistor may be determined from the expression $$R = \frac{V_m - V_t}{I_t} - R_c$$

where V_m is the mains voltage, V_t and I_t are the tube voltage and current on DC respectively, and R is the resistance of the choke. The value of the inductance is not critical but the optimum voltage surge will be obtained by the use of a choke of maximum rating, e.g., 240 or 250V.

The recommended values for the series resistor on various DC supplies and for different ratings of tube are

Table 12
Glow starter switches for AC operation

Tube Rating	Supply Voltage (AC)	Circuit	Starter Model No.
1½ ft. 15-watt	200/250	Single tube or two tubes in series	ST25
	100/130	Single tube	ST25
2 ft. 20-watt	200/250	Single tube or two tubes in series	ST25
	100/130	Single tube	ST25
2 ft. 40-watt	200/250	Two tubes in series	ST23
	100/130	Single tube	ST23
3 ft. 30-watt	200/250	Single tube	ST26
4 ft. 40-watt	200/250	Single tube	ST26
5 ft. 50-watt	200/250	Single tube (capacitive circuit only)	ST25
5 ft. 80-watt	200/250	Single tube	ST26
8 ft. 125-watt	200/250	Single tube (capacitive circuit only)	ST23
16 in. circle 40-watt	200/250	Single tube	ST26

Table 13
Values of ballast resistance on DC

Mains Voltage	Resistor Values (ohms)					
	1-80 watt (5 ft)	1-40 watt (4 ft)	1-30 watt (3 ft)	2-40 watt* (2 ft)	2-20 watt* (2 ft)	2-15 watt* (18 in)
200	103	208	264	116	182	235
210	116	235	293	128	208	264
220	128	267	330	147	235	293
230	147	293	380	147	264	330
240	166	330	420	166	293	380
250	166	330	420	166	330	380

* Two tubes in series

Table 14
Relative arc voltage and current on AC and DC

Tube			DC		AC (50 c/s)	
Wattage	Length (ins.)	Diam. (ins.)	V_t	I_t	V_t	I_t
15	18	1	60	.25	57	.30
20	24	1½	65	.31	60	.35
30	36	1	110	.27	104	.34
40	24	1½	53	.76	50	.88
40	48	1½	117	.34	108	.41
80	60	1½	114	.7	106	.85

Table 15
Power consumption on DC

Rated Tube Wattage	Nominal Tube Length	Total Power Consumption on DC		
		200v.	230v.	250v.
15	18 ins.	50 watts	57 watts	62 watts
20	2 ft.	62 watts	71 watts	77 watts
30	3 ft.	54 watts	62 watts	67 watts
40	2 ft.	152 watts	175 watts	190 watts
40	4 ft.	68 watts	78 watts	85 watts
80	5 ft.	140 watts	161 watts	175 watts

Table 16
Tungsten lamp ballast ratings

Type of Tube	Ballast Lamp Rating	Mains Voltage			
		200/210	220/230	240	250
4 ft. 40-watt Straight	Volts	115	140	151	162
	Watts	49.5	60	65	70
	Lumens	520	635	685	735
40-watt Circle	Volts	117	142	150	160
	Watts	70	80	80	80
	Lumens	705	845	850	865

shown in Table 13. A typical wire-wound resistor is illustrated in Fig. 36.

Operated on direct current, the voltage across a given fluorescent tube is somewhat higher and the arc current lower than on alternating current. Due allowance for this must be made in estimating the value of the series resistor. Table 14 shows the nominal tube voltage and current for various ratings on both DC and AC.

Inevitably the overall efficiency of the fluorescent tube and its associated controlling equipment is much lower on DC than on AC, due to the wattage loss in the necessary series resistance. For example, a 5-ft. 80-watt tube on AC and its associated choke absorb about 94 watts but on DC the total consumption would be from 140 to 175 watts, according to the supply voltage. Table 15 shows the wattage consumption of the various tubes operated on direct current.

The ordinary glow-type starter switch is not generally suitable for use on DC due to its asymmetric construction which may make ignition difficult on one particular polarity. Apart from this consideration glow switches have a higher striking voltage on DC than on AC. For these reasons, therefore, thermal switches, which are current operated, are recommended, the switch rating being selected to suit the appropriate tube current as shown in Table 14. Suitable thermal starters for use with various tube ratings are as follows:—

Tube	Starter Switch Reference
5-ft. 80-watt	ST.23
5-ft. 50-watt	ST.24
4-ft. 40-watt	ST.24
3-ft. 30-watt	ST.24
2-ft. 40-watt	ST.23
2-ft. 20-watt	ST.25
18-in. 15-watt	ST.25

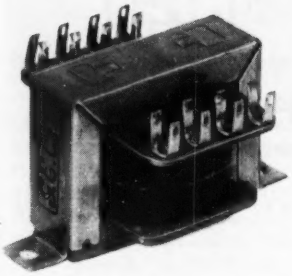


Fig. 51. Transformer for 40-watt TLC circuit.

(16.6) *Tungsten Lamp Control*

(16.6.1) FOR 4-FT. 40-WATT STRAIGHT FLUORESCENT TUBES

Mention has already been made of tungsten lamp control (TLC) circuits applied to both straight and circular fluorescent tubes The electrode heating transformer for use with 40-watt straight or circular tubes is illustrated in Fig. 51 and may be used with one or two tubes.

The tungsten ballast lamps used in TLC circuits have a designed average life of 2,500 hours and are specially rated to provide correct starting and running conditions for the fluorescent tube. These ballast lamps are generally fitted with 3-pin BC caps to prevent insertion in ordinary tungsten lamp sockets. They may be obtained with pearl bulbs or internal reflector bulbs.

The ballast ratings for different mains voltages and for operation with straight 4-ft. 40-watt or 40-watt circular fluorescent tubes are given in Table 16.

(16.6.2) FOR 40-WATT CIRCULAR FLUORESCENT TUBES

The principle of the earthed starting stripe on the straight tube could not be applied to the circular lamp owing to the practical difficulties of attaching the wire to the curved wall of the tube. Reliable starting over a wide range of mains voltage and ambient temperature variations is achieved by:—

(1) Making provision for adequate cathode heating current. This is done by an instant start transformer, the primary of which is connected across the tube instead of across the mains as in the straight TLC circuit. The tungsten ballast lamp is connected in series with the primary of the transformer, and this arrangement allows additional cathode heating current at starting without the danger of excessive cathode temperature once the lamp has started.

(2) An insulated conductor of sufficient cross-sectional area held in close proximity to the curved wall of the tube. On 220/250V supplies this starting wire is connected to the neutral terminal of the supply, and on 200/210V supplies it is connected to a special transformer tapping which is some 50V below neutral potential. A feature of this arrangement is that it ensures reliable starting in cases where no direct earth connection to the fitting is available, though an earth connection is desirable in the interests of electrical safety.

(3) Coating the fluorescent tube with a water repellent medium to reduce the effect of humidity on the striking voltage.

Four tungsten ballast lamps cover the voltage range 200/250V. These are supplied in the standard 60-watt pearl bulb and fitted with 3-pin BC caps as in the case of ballasts for the straight tube TLC circuit These are specified as ballasts numbers 5 to 8 to distinguish them from types 1 to 4 used with the straight tube. The estimated

Table 17

Overall efficiency of 40-watt TLC circuits (circular tube)

Supply Voltage		200/210	220/230	240	250
Ballast Lamp Rating	Volts	117	142	150	160
	Watts	70	80	80	80
	Lumens	705	845	850	865
Fluorescent Circle	Watts	40	40	40	40
	Lumens	1,510	1,510	1,530	1,530
Transformer Losses	Watts (approx.)	4.0	4.0	2.0	1.0
Total Watts		114	124	122	121
Total Lumens		2,215	2,355	2,380	2,395
Overall efficiency (Lm/w)		19.5	19.0	19.5	19

Table 18

Efficiency and ballast ratings for MCFB/U 4 ft. 40-watt tube

Mains Volts	Ballast Rating		Initial Lumens*		Total Lumens	Total Watts	Overall Efficiency (Lm/w)
	Volts	Watts	Tube	Ballast			
225	140	70	2,080	847	2,927	110	26.6
240	150	75	2,080	908	2,988	115	26.0
250	160	80	2,080	968	3,048	120	25.4

*Warm white.
MCFB/U tubes are also available in 2 ft. 20-watt size.

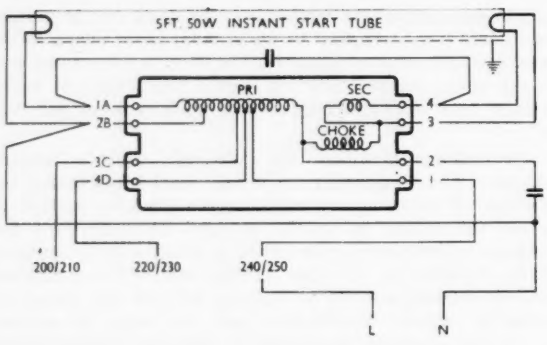


Fig. 52 Instant start circuit for 5 ft. 50-watt tube.

average life of these lamps is 2,500 hours under normal conditions.

The rating of the ballast lamps has been designed to operate the fluorescent circle at closely 40 watts and to obtain the maximum lumen output from the combination. Table 17 shows the expected lumen output and overall efficiency for the four voltage ranges covered.

(16.6.3) COLD STARTING

The arrangement described in Section (10) utilises a tube with an internal conducting stripe and a tungsten ballast lamp connected in series. This type of circuit (popularised as "Gearless") is probably the simplest circuit for operating a fluorescent tube. A standard type of fluorescent tube cannot, however, be employed and the life of the tubes, due to "cold starting," will inevitably be shorter than that of a normal tube operating on a "pre-heat" circuit.

Table 18 shows the rating of ballast lamps for various circuit voltage and the overall efficiency of the arrangement.

(16.7) *Control Gear for 5-ft. 50-watt Fluorescent Tubes*

Owing to the rather high arc voltage associated with the 1-in. diameter 5-ft. 50-watt tube it is not possible to operate it from 200/250 volt mains with straightforward choke control. A capacitive (leading) circuit may be used in conjunction with a 30-watt (thermal) starter switch. The appropriate control circuit for instant start is shown in Fig. 52.

(17) Radio and Television Interference

(17.1) *The Cause*

Electric discharges tend to generate high-frequency oscillations which may cause interference with radio or television receivers. The noise caused by the interference is rather like a rapid "frying" or crackling. Once the interference begins it seldom ceases until the tube is switched off, but a tube which has previously caused interference is often free from it when first switched on again. The fundamental causes of radio interference from electric discharges are by no means fully understood although a great deal of research work has been done on the problem. Tubes which have been in use for a considerable period are generally more prone to cause interference than new tubes, but the existence of interference is not necessarily an indication that a tube is approaching the end of life.

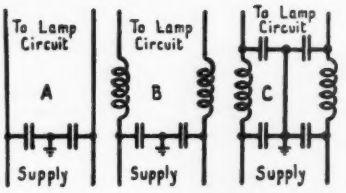


Fig. 53 Three possible radio interference suppressor circuits.

Interference is divided into two types, that which is direct etheric interference from the tube to the aerial, and that which is carried by the supply mains. With the first, the strength of the interference falls off rapidly as the distance between the receiver and its aerial is increased and is usually negligible at distances greater than 15 feet.

Radio receivers vary considerably in sensitivity and interference which is intolerable with one set may be negligible with another in the same situation and tuned to the same broadcast. Generally speaking, interference from fluorescent tubes is most noticeable on the medium wave band 200 to 500 metres. It also follows that where an inefficient aerial system is in use, and where the sensitivity of the receiver must be boosted to compensate for this, interference is more likely to be experienced. This is particularly true of indoor aerials, where a screened aerial lead is of advantage.

(17.2) *Suppression*

The first step when investigating complaints is to ascertain if the interference is actually due to a particular tube or group of tubes. Switching a tube off and on again may temporarily eliminate the interference but it usually recurs after a short time. It will also be necessary to ascertain whether or not the suppression capacitor is in circuit and operating. This can easily be ascertained by connecting a new capacitor of approximately 0.02 μF capacitance in parallel with the suspected one and noting any reduction in the interference level—it is not necessary to remove the suspected capacitor in this test.

If the interference still persists the next step is to determine whether it is mains borne or is being picked up by the aerial lead. A small battery-operated receiver is ideal for this purpose, and if when connected to the existing aerial lead, interference is still present, it is etheric in character and may be eliminated by screening or re-routing the aerial lead. Anti-interference aerials are available.

Etheric interference may sometimes be eliminated by disconnecting the earth lead from the set (if this does not result in too great a diminution of signal strength) or by re-routing the earth lead.

In addition to the above remedies which are associated with the receiver and its associated aerial/earth system, the fitting itself may be surrounded by a $\frac{1}{2}$ in. to 1 in. woven wire mesh electrically bonded to a good earth. Such a solution may, however, be unacceptable as being unsightly.

If the interference is mains borne it may be necessary to fit some form of mains filter across the terminals of the fitting or of the receiver or both. Fig. 53 shows three possible types of filter arrangements: (A) consists of two 0.1 μF capacitors centre tapped to earth; in (B) two 1 mH chokes, each capable of carrying the full circuit current, are used; arrangement (C) is somewhat more elaborate. It is difficult to say which of these filters is the most effective, and it is suggested that they be tried in the order shown

PART 3: TESTING AND MAINTENANCE

(18) Testing Fluorescent Tube Circuits

The satisfactory operation of a fluorescent tube is clearly dependent on its operating under the conditions for which it was designed. If the appropriate choke coil is used for the average mains voltage concerned, the tube should consume, at least on normal switch-start circuits, a power very close to the rated tube watts; this can be derived from the product of tube watts, current and a form factor of approximately 0.9.

The accurate measurement of tube watts in switchless circuits employing transformers which provide continuous electrode heating is considerably more difficult. One method is to subtract the estimated losses in the auxiliary gear from the total circuit watts, but generally speaking, it will be sufficient guide to measure the actual tube voltage and assume, if this is normal, that the tube wattage is also normal. The circulating current in the electrodes both at starting and running should, of course, be within the limits specified by the tube manufacturers.

On switch-start circuits the starting and running conditions of fluorescent tubes and control gear may be measured under actual working conditions with a simple adaptor without any alteration to the fitting or wiring. One form of adaptor is shown in Fig. 54 and consists of a small switch block with an inset canister socket, four insulated terminals, and two press switches. The adaptor is wired up as shown in Fig. 55, one of the press switches being normally open circuited and the other short-circuited in the " off " position.

Two sets of leads may be required, one for use with fittings using canister-type starters and one for fittings made for use with the now obsolescent SBC starter and tubes with BC caps. The former consists of two canister starters with the switches and suppression capacitors removed (Figs. 56a and 56b). For testing 80-watt tubes with bayonet caps and SBC glow starters, the lead consists of a canister starter with switch and radio suppression capacitor removed, BC and SBC adaptors and BC holder (Figs. 57a and 57b).

It will be seen from Fig. 55 that the function of the press switch 'A' which is normally open, is to short-circuit the usual glow starter switch contacts: when pressed and released after a few seconds the switch acts as a

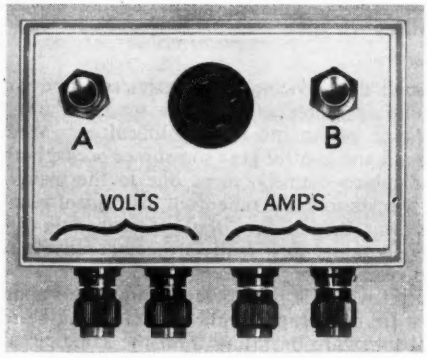


Fig. 54. Simple adaptor for testing starting and running conditions of fluorescent tubes and control gear.

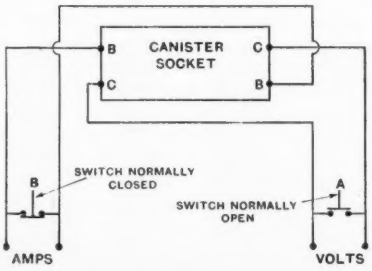


Fig. 55. Wiring for adaptor illustrated in Fig. 54.

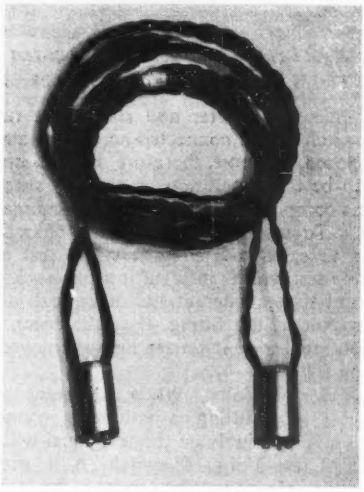


Fig. 56a. Test lead for fittings having canister type starters.

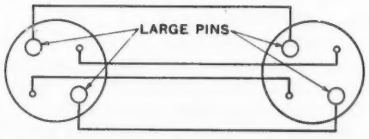


Fig. 56b. Wiring of test lead shown in Fig. 56a.

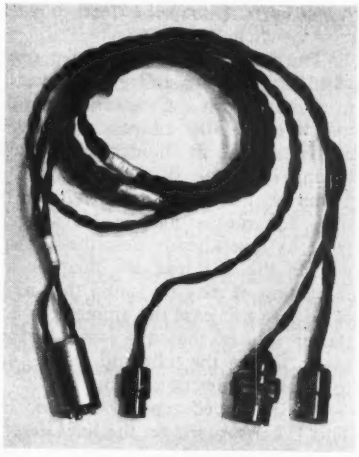


Fig. 57a. Test lead for testing 80-watt tubes with bayonet caps and SBC glow starters.

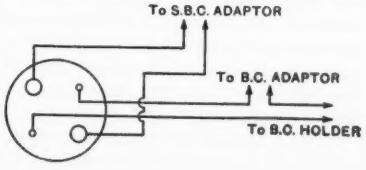


Fig. 57b. Wiring diagram for test lead shown in Fig. 57a.

Fig. 58 (left). A fluorescent lamp test set.
Fig. 59 (right). Adaptor for short circuiting bi-pin lampholders.

"manual" starter and strikes the tube. The press-button switch 'B' is connected across the ammeter and is normally closed. It must, therefore, be depressed for current readings to be taken and acts as a safety shunt to the meter as well as completing the circuit when the meter is not connected.

To measure the operating characteristics of tubes used with canister-type starters, the test canister at one end of the test lead is inserted into the socket on the adaptor panel and the canister at the other end is inserted in the starter socket in the fitting, the tube being in place in the fitting but the normal starter being removed. Readings are taken as follows:—

Mains Volts. When the mains are first switched on to the fitting a voltmeter connected across the volt terminals on the test panel will register mains volts.

Lamp Volts. If switch 'A' is pressed and then released after about two seconds the lamp should strike and the voltmeter will then register the voltage actually across the tube.

Starting Current. If switch 'B' is pressed at the same time as switch 'A,' an ammeter connected between the amps. terminals on the test panel will register the tube starting current.

Running Current. When the tube is running, the running current may be read on the ammeter by pressing switch 'B' alone.

The second set of leads, for use with the 80-watt tubes with bayonet caps and glow starters with SBC caps, is used in a similar way. Connection at the fitting end is made by inserting the SBC adaptor into the SBC starter socket, disconnecting the BC holder from one end of the tube and inserting in it the BC adaptor, and finally placing the BC holder on the lead on the free end of the tube. The procedure for measuring the lamp characteristics is then the same as that already described. As there are two ways of putting the test lead BC adaptor into the lamp-holder on the fitting, it may be found that no running current is indicated. In this case the ammeter is actually connected on the starter side of the tube instead of being connected on the mains side of the tube and the BC adaptor must be reversed to obtain a current reading.

An improved type of adaptor is illustrated in Fig. 58. This is constructed on the lines described above but includes the refinement of a change-over switch for volt or ampere readings for use with a universal meter. It also has several different types of starter socket wired in parallel with the four-way lead so that various starters may be tried out on the bench without the necessity of climbing up and down to the fitting under test.

The approximate lamp operating characteristics for all ratings of lamps in inductively controlled circuits are given in Table 3. In capacitatively controlled circuits the tube-starting current is materially the same as the running current. It must be remembered that the tubes take a few minutes to achieve complete stability, particularly if the ambient temperature is low.

The power factor of an uncorrected tube circuit, due to the inductance of the choke coil, is approximately 0.5; the tube and mains current will be as quoted in Tables 3 and 4. When the power factor is corrected by means of the recommended capacitor the lamp current will be unaltered, but the mains current will be reduced.

Where the tube attempts to strike but will not remain alight it is helpful to know the operating conditions, as the fault may be due to (1) low mains voltage; (2) correct mains voltage but abnormally low tube current due to incorrect gear; (3) faulty starter switch, or (4) faulty tube. (1), (2) and (3) may be checked by the method described above.

If the tube has failed by passing excessive current, it is inadvisable to install a new lamp before checking the circuit conditions. This is done by short-circuiting the two lamp-holders in the fitting concerned and measuring: (a) the short-circuit current of the choke coil; (b) the voltage across the starting switch. Convenient adaptors for short-circuiting the lampholders can be made from (a) BC adaptors for use with BC tubes, or (b) bi-pin caps short-circuited between the pins and mounted as in Fig. 59 for bi-pin tubes.

The short-circuit current should not materially exceed the rated starting current of the tube; if it does, or if the circuit fuse is blown, there is probably a fault in the choke coil or an earth fault in the wiring. If the voltage across the starting switch is greater than the mains voltage, the power factor capacitor is connected across the tube and not across the mains, thus forming a partially resonant circuit. If there is no reading on the voltmeter there is probably an open circuit which may be due to (1) a disconnection in the wiring, or (2) a broken tube electrode.

(19) Servicing

(19.1) *General*

Although the servicing of a fluorescent tube installation is not quite as simple as that of a tungsten-lamp installation it should present no serious difficulties. Minor faults in the circuit and control gear sometimes occur, but the only likely difficulties—namely, those due to the mains voltage, ambient temperature, the tube itself, its control gear or some maladjustment thereof—are those described in this guide. Generally speaking, such faults are comparatively simple to trace and remedy.

A circuit which is not operating properly should be disconnected from the supply until the defect can be remedied; if several tubes are operating from the same circuit switch the tube giving trouble should be removed and the particular circuit locally isolated. A new tube should not be tried in a circuit which has been operating abnormally unless it has been established that the circuit itself is not faulty or until the original fault has been rectified. Some manufacturers are now supplying fittings incorporating replaceable fuses.

Abnormal operation under low ambient temperature conditions has been dealt with in Section (4.8), but trouble from this cause alone is infrequent, as low temperatures, at least in this country, are generally associated with low mains voltage due to the increased total cable loading. As the mains voltage falls, the current through the tube is decreased and the voltage across the tube rises. If the tube is operated with a glow-type starter under such low mains voltage conditions the voltage across the tube and starter may rise to a value sufficient to cause reclosures of the starter contacts, resulting in continuous "blinking." Alternatively, if a thermal-type starter is being used the reduction in tube current, and hence

Table 19

Tracing faults in lamps in service

(A) TUBE ATTEMPTS TO STRIKE			
(1)	Tube	(a)	Life expired
		(b)	Faulty tube
(2)	Starter	(a)	Contacts break too quickly (glow or thermal types)
		(b)	Low extinction voltage (glow type)
		(c)	Incorrect rating of starter (thermal type)
(3)	Control gear	(a)	Incorrect choke or choke tapping
		(b)	Incorrect capacitor in capacitive circuit
(4)	Wiring	(a)	Heater coil and switch contacts of thermal type switch reversed
(B) TUBE ELECTRODES GLOW CONTINUOUSLY			
(1)	Tube	(a)	With switchless start control gear wrong type of tube installed
		(b)	Stripe on striped tube not earthed
(2)	Starter	(a)	Switch contacts stuck together
		(b)	Suppression capacitor broken down
(3)	Control gear	(a)	Suppression capacitor broken down (switchless circuit)
		(b)	Insufficient electrode heading (switchless circuit)
		(c)	Incorrect values of circuit component (switchless circuit)
(4)	Fitting	(a)	Fitting not earthed (switchless circuit)
(C) TUBE WILL NOT ATTEMPT TO STRIKE			
(1)	Tube	(a)	Broken electrode
		(b)	Cracked tube
		(c)	Faulty tube
(2)	Starter	(a)	High striking voltage (glow type)
		(b)	Broken bi-metal (glow or thermal types)
		(c)	Cracked bulb
		(d)	Open circuit in heater coil (thermal type)
		(e)	Wrong rating of starter (thermal type)
		(f)	Heater coil in contact with bi-metal (thermal type)
(3)	Control gear	(a)	Open circuit in choke
		(b)	Open circuit capacitor (capacitive circuit)
		(c)	Faulty transformer (switchless circuit)
(4)	Wiring	(a)	Disconnect in wiring
		(b)	Bad contact in lampholders or sockets
		(c)	Incorrect wiring

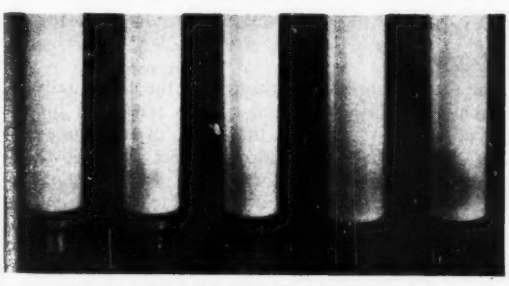


Fig. 60. End blackening of fluorescent tubes.

the current through the heater coil of the starter due to the low mains voltage, may result in reclosure of the switch contacts. It is also possible that the reduced tube current will be insufficient to keep the electrodes up to emissive temperature, resulting in unstable operation apart from irregular operation of the starter switch.

Assuming that the external conditions are sensibly normal a tube may (A) attempt to strike; (B) glow continuously at the ends, or (C) may not attempt to strike at all. The possible sources of trouble in the three cases are given in Table 19.

(19.2) *Tubes*

The most likely cause of tube failure is that it has had its normal life. As has already been mentioned, the active electrode coating is necessary for starting and maintaining the discharge. When a tube is nearing the end of its life this electrode coating is nearly exhausted but the electrodes, still being electrically intact, complete the circuit through to the starting switch. The switch contacts, therefore, open and close, and the voltage surge causes a momentary "blink" in the tube, but, because the electrode coating is exhausted, the discharge through the tube is not maintained. This cycle is then repeated by the continued periodic operation of the starting switch, and there is a periodic "blinking," usually accompanied by a shimmering effect in the discharge. A further indication that a tube is nearing the end of its life is the deep orange-coloured glow of one or both electrodes.

At the end of their life fluorescent tubes generally show a dense blackening at one or both ends, either in the form of general blackening or as a clearly defined ring near the electrode. This end blackening is progressive throughout the life of the tube, and Fig. 60 shows examples of a typical tube before use, at 1,000 hours, 2,000 hours, and at the end of life. Sometimes also, dark streaks or small dark patches may appear along the length of the tube. This is due to condensation of the mercury vapour on the lower, and therefore cooler, part of the tube. Rotation through 180 deg. will give a more favourable position for evaporation.

Cracked tubes and broken electrodes should be obvious from visual examination or by testing the electrodes with any normal form of continuity tester. If only one electrode is broken a faint glow at this end of the tube may be noted, as some of the mains voltage will exist across the broken ends.

If the tube is faulty from other causes it will probably try to start in a similar manner to a lamp which has had a normal life and whose electrode coating is exhausted.

(19.3) *Starting Switches*

(19.3.1) GLOW TYPES

The satisfactory operation of the glow starter switch depends on its voltage and time characteristics. For example, if the "striking voltage" of the glow switch is too high, the switch contacts will not close and the lamp discharge will not start. Again, if the "extinction voltage" of the switch is too low, the switch contacts will tend to close after the tube has struck, causing periodic blinking. The switch will also tend to close if the voltage across the tube is abnormally high, either due to low mains voltage or to the use of incorrect ballasting.

If the switch contacts, through some fault or incorrect spacing of the bi-metal strip, operate too quickly, the tube electrodes may not have time to heat up before the switch contacts open again, producing repeated flashing and accelerated dissipation of the electrode coating. On the other hand, if the switch contacts operate too slowly, the tube electrodes will be unnecessarily overloaded. Clearly, therefore, the "relative ease" of the start is important and a switch that does not start a good tube in a few seconds should be replaced.

A normal switch will, however, outlive several tubes, and whilst the lamp life is to some extent influenced by the total number of switchings throughout life, the lamp may be switched many thousands of times before any substantial effect on switch performance is likely to be noted.

(19.3.2) THERMAL TYPE

As with the glow switch, the thermal switch contacts must not break too quickly, or the electrodes will have insufficient time to become incandescent; also, the thermal current rating must correspond to that of the tube. Thus a thermal switch suitable for a 20-watt lamp may operate too quickly with a 40-watt lamp and an 80-watt thermal switch may not operate at all on a 40-watt circuit. Use of an incorrect rating may also result in the heater coil burning out. Continuity of the heater coil may be checked across the smaller pair of contacts of the canister-type switch.

(19.4) *Chokes and Capacitors*

Intermittent working or bad starting may be due to the wrong value of inductance or capacity in series with the tube. As the tube current is controlled by series equipment, too low a series impedance will result in overloading of the tube and auxiliaries and too high a value of impedance will result in inadequate current and uncertain operation. The starting and operating current should, therefore, be measured if the control gear is suspected.

An open-circuited capacitor connected in series will, of course, result in non-striking of the tube, but if connected in parallel, will only be obvious if the mains as well as the tube running current is measured. Capacitors should take about 72 mA per μF at 230 volts, and can be tested by connecting them across the mains with a meter in series.

Short circuits in chokes and capacitors, though rare, can have more serious effects as previously mentioned. A short circuit or partial short circuit in a choke is best checked by connecting the suspected choke in series with a similar choke across the mains and measuring the division of voltage across the chokes. A normal choke of any particular rating may be connected directly across the mains and the current taken should not be materially in excess of the tube starting current.

(19.5) *Wiring Faults*

An earth fault in the wiring of a fluorescent fitting can cause complete destruction of one or both tube electrodes, the starting switch, and damage to the choke coil itself. The effect of this fault will, of course, depend on the particular position of the earth in the circuit and the manner in which the phase and neutral leads are disposed. A tube overloaded in this manner generally shows quite clear visual indications; the electrodes are blown off, the lead-in wires are fused and the electrode coating volatilised on the tube walls.

Because, during the starting period, momentary voltages of the order of 800 to 1,000 may be produced, breakdown may occur in the wiring or in the radio suppression capacitor if the insulation of these components is poor. Breakdown of the latter may cause a short circuit across it which will short circuit the tube in which case the electrodes will glow continuously and the tube will make no attempt to start.

If the choke coil is connected in the neutral of the mains supply an earth fault on the wiring between the choke and the tube or on the wiring associated with the starter switch will short circuit the choke so that there is no limit to the current and the tube electrode and starting switch will be damaged or destroyed. On the other hand, if the choke is connected in the phase lead an earth fault will place the choke across the mains, which will slightly overheat the choke, but as the choke is still limiting the current to some extent, the electrodes or the starting switch will not be seriously damaged if the circuit is switched off in reasonable time.

It is recommended, therefore, that the choke should be connected in the phase lead of the supply. If it is suspected that a previous tube failed through an overload, the fitting should be checked over for earth faults before a new tube is installed.

If the tube in the capacitive branch of the twin-tube circuit is connected across the capacitor, catastrophic overloading will occur due to a high resonance voltage developing across the capacitor. The same effect is produced by connecting the ordinary parallel PF capacitor across the tube instead of across the mains.

It is important to ensure that the heater coil of a thermal starter is wired between the choke and tube electrode and not between choke and mains lead. In the latter case the surge voltage is applied between heater and switch contacts and is likely to cause switch breakdown.

(19.6) *Premature Blackening*

Excessive blackening of the ends of the tube occurring early in life indicates that the electrode coating is being dissipated too rapidly owing to abnormal operating conditions, which may result from any of the following causes :—

(1) Overloading due to excessive mains voltage.
(2) Overloading due to incorrect choke or capacitor or defects therein.
(3) Defective starting switch causing tube to blink on and off or prolonged flashing at starting.

It must be remembered that low voltage and ambient temperature conditions will cause bad starting, and bad starting, if prolonged, will result in premature blackening.

The choke rating and average mains voltage should be carefully checked and, if necessary, the starting switch replaced. A fault in a choke coil is rare, but when it does occur it is sometimes not easily traced by visual inspection. A serious fault may give rise to burnt insulation or seepage of the wax through the metal container.

(19.7) *The Disposal of Spent Fluorescent Tubes*

Because the tubes are evacuated, breakage by accident or design results not only in the usual danger from breaking glass but from flying glass splinters. The inrush of air will also disperse the powder, and whilst most fluorescent tubes are coated on the inside with a powder which does not constitute a hazard when the tube is broken up, it is obviously undesirable to create a lot of dust.

All this can be avoided quite easily with tubes having bi-pin caps by holding the lamp vertically and striking the opposite end against the bottom of a dustbin or other container. It must be struck sufficiently hard to push the base pins through the glass and thus destroying the vacuum. Tubes having BC caps cannot be treated in this manner. To destroy the vacuum the shoulder of the lamp (where the glass meets the cap) should be tapped smartly with a file or thin metal road. To eliminate any danger from boken glass the end of the lamp should have a rag wrapped round it. In both cases air is admitted and eliminates the possibility of flying glass splinters and powder dispersion caused by the collapse of the tube. The glass tube can then be smashed up piece by piece with a metal rod.

(20) Conclusion

The art of fluorescent lighting and the continually changing fashion in tube types and circuits renders it difficult, if not impossible, to be certain that much of the data contained in this guide is current or indeed correct. It is, however, the hope of the authors that it will be at least a "guide" in a subject which has so many different facets.

It has not been possible to include gear made by, and data published by, all and every different manufacturer of tubes and equipment, but it is hoped that the information provided is representative.

HOME LIGHTING

The concluding part of a series by Derek Phillips, M.Arch. (M.I.T.), M.C.D., B.Arch. (L'pool), A.R.I.B.A.* Throughout the series, sketches of suggested schemes have been by the author.

PART 6 - - - - - - The outside of the house

A CLOSE relationship between indoor and outdoor space raises problems of artificial lighting which are not always apparent to architects. So often, the daytime effect of a striking modern home in Britain or America is spoilt at night. In spite of the current vogue of attractive lighting fittings, there is little attempt to use artificial lighting to make the inside and the outside of the house act together. It seems a pity to "bring the garden into the house" or "extend the house into the country" only during the day, for there is a growing tendency to use the garden as an extra room, even in Britain's fanciful climate.

"Active" outdoor pleasures may be for the few, but the extension of view at night can be enjoyed by all. There are, of course, many evenings when we draw the curtains to shut away the rain and cold outside, but there are also many lovely long spring, summer and autumn evenings when it is a delight to relax in a garden, or to view the garden from the comfort and warmth indoors.

The Approaches and Entrance

The entrance to a house has always been of importance. In the past it has generally derived scale and significance from decoration and moulding. The entrance to a modern house is rarely imposing, but it should be welcoming, so that on arrival or return there is an air of warmth. This atmosphere is often easy to provide, particularly where the hall itself is clearly visible through translucent panels. So long as the back wall of the hall is well lit, the hall will appear bright and, if the translucent panel extends to floor level, there should be sufficient "spilt" light to illuminate the area immediately outside the door. If there is not sufficient light a small lamp (60-100 watt) should be used for this purpose, in a fitting that conceals the lamp from normal approach angles.

If there is a porch, it is again easy to add emphasis and create a sense of welcome. The level of illumination on the ground below the porch should be between the level indoors and the level outdoors—say 1 lm/ft², and it is important to light the underside of the porch. A good example of porch lighting is seen in Fig. 1: a concrete arch acts as a porch and, at night, to lend emphasis to the approach, it is lit by two inverted reflector fittings containing small tungsten filament lamps.

If there is a drive, it can be lit by small path-lighting columns such as those used at the Detroit plant of General Motors (Fig. 2). These fittings, which are 3 ft. 6 in. high, light an area about 60 ft. diameter. Reduced to domestic scale, they would give sufficient light on a drive for safe walking at night.

Not to be forgotten, though they present little difficulty, are the back door, or the tradesmen's entrance, the garage and the outhouses.

The Gardens

For the lighting of the gardens, innumerable lessons can be learnt from the lighting of public gardens—in particular, perhaps, the Tivoli Gardens in Copenhagen. Here co-operation between the landscape architects, the building architects and the lighting engineers has produced a wonderland of magic. The most important lesson is delicacy of touch, typified by the treatment of a small walled garden full of wooden fountains. Each fountain has three miniature lamps set into the side of the wooden bowl and aimed to give a small crossed beam at the apex of the spout of water (see Fig. 3). Another example is the hanging baskets of flowers which are lit from above (by a simple louvred fitting) and around the edge so that the flowers are illuminated, as are the cylindrical sides of the baskets. The vertical wooden slats which shield these baskets appear in silhouette (Fig. 4).

Fig. 5 shows a simple solution to the problem of lighting the garden of a house whose owners wished to have a "flow of space" between the inside and the outside. A composite lighting fitting has a main reflector, giving upward light to the underside of the canopy above the "outdoor room,"

Fig. 1. Porch of house at Carlisle (Architects, Ryden and Yates).

* Consultant architect to the A.E.I. Lamp and Lighting Co., Ltd.

Fig. 2, pathway light, 3 ft. 6 in. high, at General Motors Technical Centre, Detroit.

while a second reflector gives a direct component of light to the group of chairs and tables below.

Fig. 6 is a more elaborate scheme in which 50 lamps with a total rating of about 5 kw, were used. The main lighting of the sitting area comes from a plastic "bubble fitting" containing three 75-watt lamps. Light for the translucent screen comes from 21 reflector lamps trained on it from behind, some of these lamps having coloured filters so that the colour of the screen can be changed. Other fittings include wall brackets, standard lamps, floodlights, and single and double mushroom fittings for lighting the flowerbeds.

Each garden or landscape has its own problems but, as a basic method of approach, I suggest the following :—

i. Draw a plan of the garden, marking in the permanent plants and shrubs, their heights, etc.

ii. Plan a permanent electrical circuit to take in the areas in which a permanent lighting scheme is contemplated.

iii. Allow for a degree of flexibility, by the provision of weatherproof plug points where it is likely that additional lighting may be needed.

iv. Choose a scheme of lighting which is in scale with the architecture and the landscape—a little goes a long way.

v. Attempt to arrange for lighting units to be placed at different distances from the normal viewing point. This arrangement will add the perspective which is generally lacking at night, and add to the desired effect of extending the view.

Equipment for garden lighting is more easily obtained in the United States than in Britain, but a demand will almost certainly create a supply, as it is easy to produce simple weatherproof equipment. Most light sources can be used, tungsten being usual for flower beds, as it gives the closest approximation to the colour rendering we expect from flowers at night. Coloured filters and mercury- or sodium-vapour lamps can be used to emphasise trees or distant objects.

A hypothetical scheme embodying some of these ideas is shown in Fig. 7. The plan indicates a typical modern garden, about 50 ft. long. The perspective (a view from the terrace) attempts to show the effect that might be created by the following installation:—

i. Terrace: 150-watt reflector floods mounted below the eaves of the house.

ii. Pond: 3-ft. 30-watt 1-in.-dia. fluorescent lamps mounted below overhanging edges. Capable of being withdrawn for maintenance.

iii. Dividing fence: Single 200-watt reflector floodlight trained along the fence at an angle from right to left.

iv. Flower bed: 75-watt tungsten lamps in mushroom fitting.

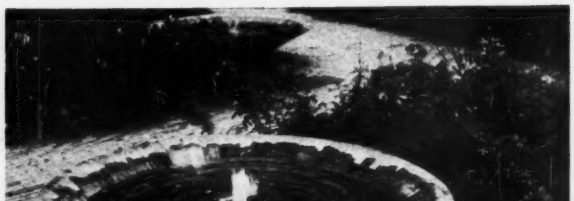
v. Tree: Blue fairyland strip (15-watt lamps).

(N.B.: i, ii and iii constitute the permanent installation; iv and v would be flexible and could be altered whenever required.)

The Internal Lighting

The need to prevent "views through the windows after dark from being marred by unpleasant reflections" has been stressed previously (Article 2. *Light and Lighting*, March, 1957, p. 91). If the garden is very bright there is no difficulty; usually, however, gardens are not very light and, if the windows facing the gardens are closed, any bright area of the room—particularly a light source—will be seen mirrored in the glass. In fact, you cannot have your cake and eat it: if light is required in the room it is difficult to avoid reflections. It is helpful if the sources can be shielded, as reflections then depend on the reflection factor of the furnishings.

When television is being used the screen should be turned away from the window. It is then possible to



Tivoli Gardens, Copenhagen: Top, Fig. 3, garden fountain; above, Fig. 4, hanging basket, internally lit.

look at the lit garden as a rest from the concentration of viewing, without seeing any reflected image of the screen.

The External Appearance

The greater use of glass and the greater use of the garden have added to the importance of the external appearance of the house at night. Good lighting can greatly assist in creating an external appearance that expresses the interior character and use of the house. Fig. 8 shows a new house at Rickmansworth in the design of which the architect, Edward Curtis, A.R.I.B.A., Dip. Arch., has emphasised the interior staircase. There is a mural by Cecil Stephenson on the staircase wall and the total effect is a challenging statement of the function and decorative nature of the interior. The lighting appears to be efficient inside the house and "expressive" from without, as well as giving light to the immediate garden area. Each home has a different character to be expressed, but the general effect seen in this illustration may well be typical of good home lighting of the future.

CONCLUSIONS

Looking back on the somewhat pompous aim in this series of articles:—

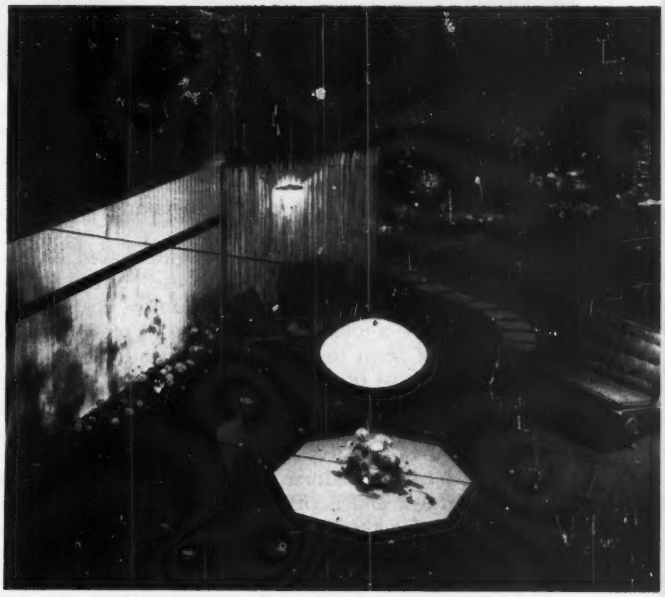
> ". . . to draw to the attention of architects as much as to lighting engineers, the relationship between lighting and house design, as it affects Man's home environment and the formal unity of house design,"

it is a little difficult to know to what extent I have deviated from this high purpose. I take comfort in the phrase "the relationship between" since this clearly indicated that the series was not intended to show how existing equipment can best be fitted into the home. The purpose has been to analyse the problem, and to discuss what type of solution might be developed to solve it. The modern home differs widely from the traditional home and needs different lighting, but I believe that the approach to lighting a home of any period must be based on principles, rather than on customs, for if custom denies principle, then it is the custom which must be abandoned.

Some of the criticisms of this series of articles have been levelled at the concepts of modern architecture itself that I have expressed. Whilst I believe that a healthy questioning of such concepts as "the free plan" and "built-in furniture and fittings" is perfectly valid, the series was not intended to be a defence of modern architecture. However, the static nature of built-in furniture in rooms such as the kitchen, the bedroom, and the bathroom, and in storage areas, assists the lighting engineer, while in the living room there is to-day much more flexibility than there was in the past.

Professor Rasmussen (*R.I.B.A. Journal*, July 1957, p. 360) speaks of a home in Denmark for which a leading architect designed ". . . not only the whole structure, but the complete interior, with furniture, textiles and lamps." On visiting the house he felt that it "looked more like an exhibition of an ideal home, than a home ideal for the people who lived in it." In suggesting that the architect should design the entire lighting arrangements, this is a very real danger, which raises the question: "Who should be responsible for what?"

A distinction might be made between those parts of a house that can be altered without destroying its fundamental architectural quality—e.g., curtains, furniture, carpets, colour schemes and pendant and portable lighting fittings—and those parts which are closely related to the form of the building. The former should be the responsibility of the owner; the latter, the responsibility of the architect. Thus, the architect's terms of reference extend from the structure, spatial relationships and permanent surfacing materials to built-in furniture and fittings, and the integrated lighting equipment.



Top, Fig. 5, lighting of porch and outdoor sitting area by dual-purpose fitting. Above, Fig. 6, elaborate outdoor lighting scheme (General Electric Co., U.S.A.).

One question which I have been asked is: "To what extent can the ideas put forward be applied to existing houses?" While not limiting myself to ideas for old buildings, I have attempted, where possible, to describe methods applicable to them, and it is certainly true to say that all the "principles" of lighting put forward could be applied, though some of the actual schemes suggested are intended for new homes.

It may be useful to have some guide as to the difference in expenditure on lamps and gear for interior lighting between what is, at present, regarded as the "average" home and a composite scheme based on some of the ideas

Left, Fig. 7, hypothetical small modern garden—the subject of an outdoor lighting scheme described in the text. Below, Fig. 8, Solar House, Rickmansworth, designed by Edward J. W. Curtis, A.R.I.B.A., Dip. Arch. Lighting for entrance, vertical circulation area, display space (for pottery, etc.) and garden. Behind the striped "Plyglass" screen is the dining area. (Photograph by courtesy of the "Architect and Building News.")

put forward. For the 13 million users of electric current in the country, lighting is said to represent 13 per cent. of the current used. The average household, which does not light its home to the standards of the IES Code, is said to spend 30s. a year on current and 12s. on lamp replacement —a total of £2 2s. a year.

A scheme for a three-bedroom house based on the ideas in this series of articles might use current to the value of £10 a year, while lamp-replacement costs would be about £3 13s.—a total of £13 13s. This increased expenditure does not seem to be disproportionate when compared with the cost of running other electrical devices in the home. It should be noted, however, that no figure has been included for the cost of lighting fittings, as such a figure would vary widely according to individual choice.

Finally, I cannot endorse too strongly the remarks of Mr. Penny (*Light and Lighting*, Jan., 1957) on the supply of equipment for the home-lighting market. There is certainly a need for fluorescent equipment designed for the home and much could be done with a simple "fluorescent lighting pack," the gear of which could be concealed remotely from the lamp.

COMMENT: From an architect

What an interesting treatment of the subject this has been! Domestic lighting is almost always discussed either in terms of household visual "tasks" or in terms of the equipment sold over the counter. The idea of thinking within the context of contemporary house design as a whole, with the lighting as part of the concept, seems not to have been taken up previously. And the link of indoor to outdoor lighting has been a neat touch with which to finish. The whole series has been well worth while.

COMMENT: From a lighting engineer

I agree that the approach and entrance are important. I am not convinced by this fashion for mixing house and garden but Mr. Phillips has shown ways of doing it if people want it and have a garden worth looking at. He has also shown how home lighting can be made interesting —though I am against making domestic interiors look like scaled-down models of luxury hotels. I don't agree with all the suggestions Mr. Phillips has made, but he has certainly made me think, and I hope many other also.

Lighting Abstracts

LAMPS AND FITTINGS

621.327.534.2

516. The effect of outer jacket fill pressure and arc tube pressure on mercury lamp performance.

J. M. HARRIS, *Illum. Engng.*, **51,** 363-368 (*July*, 1957).

Oxidisation of the metal components in the outer jacket of a high-pressure mercury-vapour lamp is prevented by filling the jacket with an inert gas (nitrogen). The optimum pressure of this gas is a compromise between heat loss from the quartz arc tube (governing warming-up time) and arc-over voltage between the metal components. The operating pressure of the arc tube influences the colour, efficiency and life of the lamp. Arc tube discoloration has a large effect on lumen maintenance but only a small effect on the colour. P. P.

517. Converter equipment. 621.327.534.15

S. KRASNOW, *Illum. Engng.*, **52,** 353-356 (*July*, 1957).

A rotating type of frequency converter has been specially developed for energising high-frequency fluorescent lighting installations. With a capacity of 30 KVA., it produces three independently phased outputs of either 400 or 600 volts at a frequency of 840 cps. By using a permanent magnet generator, the more usual brushes, slip-rings, commutator, exciter, etc., are dispensed with. By combining harmonic frequencies of proper amplitudes, a triangular waveform is produced in the generator output, which in turn gives an optimum square waveform in the capacitative lamp circuits. P. P.

518. Circuits for fluorescent lamp ballasts. 621.327.534.15

W. W. BROOKS, *Illum. Engng.*, **52,** 397-408 (*Aug.*, 1957).

Eighteen years of practical fluorescent lighting have resulted in the evolution of several hundred different lamp-operating circuits. A systematic tabulation of these circuits has now been made and is presented in the form of brief descriptions of the principle design developments accompanied by 48 line diagrams of the circuits themselves and 11 illustrations of ballast core sections. P. P.

621.327.534.15

519. Elements of high-frequency fluorescent lighting.

J. H. CAMPBELL, *Illum. Engng.*, **52,** 337-342 (*July*, 1957).

Conventional fluorescent lamps have a higher luminous efficiency and can be operated at a higher wattage when used at a higher frequency than that generally available from the public electricity supply. Increased operating frequency also results in smaller ballasts, so facilitating luminaire design. A magnetic frequency multiplier used in conjunction with a capacitor ballast to give a square wave output is a promising form of supply but is at present limited in its frequency and power output. P. P.

LIGHTING

520. Lighting systems for grading lumber. 628.977

D. M. FINCH, *Illum. Engng.*, **52,** 373-380 (*July*, 1957).

The initial grading of timber in Californian sawmills comprises the inspection of rough-sawn planks up to 20 ft. in length as they pass on a chain conveyor belt in front of the graders. The visual tasks involved in identifying 41 types of defect were measured with a visibility meter, when samples of timber containing these defects were viewed at 20 ft. on mock-up conveyors illuminated by directional incandescent and line and diffuse fluorescent sources. The results were used to compile an IES technical report on sawmill lighting. P. P.

628.977

521. Lighting for sawmills: Redwood green chain.

Illum. Engng., **52,** 381-392 (*July*, 1957).

Compiled by the Sawmill Lighting Sub-Committee of the American IES, this report gives recommendations on the artificial lighting to be used for the initial grading of rough-sawn Californian redwood as it moves in front of the graders on a chain conveyor belt (the green chain). Best results are given by directional incandescent lighting, with the units mounted parallel to the length of the boards and tilted at a fairly steep angle to the direction of movement of the boards. An illumination of at least 100 lm/ft² is required. The grading area should be enclosed and painted a medium grey (45 per cent. reflection factor). P. P.

621.327.534.15

522. Applications of high frequency fluorescent lighting.

Q. D. DOBRAS, *Illum. Engng.*, **52,** 343-348 (July, 1957).

The problems of power distribution and heat dissipation become excessive when high levels of artificial illumination are to be provided. By using fluorescent lamps operating at high frequencies (approx. 400 cps) these problems are considerably reduced. Applications of high frequency systems to plant growth studies (1,600-2,400 lm/ft²) and to the lighting of electronic assembly plants (450 lm/ft²) and air-conditioned offices (100 lm/ft²) are described. P. P.

628.921

523. Pre-determination of natural daylight in rooms.

R. VOLLMER, *Lichttechnik*, **9,** 407-9 (*Aug.*, 1957). *In German.*

The author describes the basis and method of use of the Waldram diagram and he reproduces a modification of this diagram drawn so as to take into account the variation of luminance of the overcast sky from zenith to horizon. The Moon-Spencer formula expressing this variation, viz. $L\alpha = \frac{1}{3}L_z \ (1 + 2\sin\alpha)$ where L_z is the zenith luminance and $L\alpha$ the luminance at an angle of elevation α, was adopted by the CIE in 1955 and has been used for the new diagram. Photocopies of the diagram are obtainable from the author at Helmholtzstr. 4-8, Berlin NW 87. J. W. T. W.

628.972

524. Lighting of indoor locations of central station properties.

Illum. Engng., **52,** 423-438 (*Aug.*, 1957).

Prepared by the American IES Committee on the Lighting of Central Station Properties, this recommended practice, one of five now available on electricity generating stations, deals with the interior lighting. Thirty-six different indoor locations are described and individually illustrated, and recommendations are given on their illumination levels and special lighting requirements. The relative merits of different types of luminaire are listed, and a chart is given enabling spacing-to-mounting height ratios to be determined from luminaire polar curve data. Emergency lighting and the luminaire maintenance problems associated with generating stations are also dealt with. P. P.

The Architect and Lighting

Report on a seminar recently held at the York Institute for Architectural Studies when teachers of architecture and practising architects and lighting engineers discussed matters of common interest.

The York Institute for Architectural Studies organised a Seminar on Lighting for teachers of architecture and others from September 12-15, 1957. The purpose of the course was to give teachers of architecture an idea of recent developments in lighting which they could pass on to their students, and if possible to encourage post-graduate work in the subject. Most of the leading architectural schools were represented. The lecturers were Mr. C. Dykes Brown and Mr. A. Wilcock representing the IES, Mr. David Medd of the Ministry of Education, Mr. Derek Phillips, an architect specialising in lighting, Mr. W. Allen of the Building Research Station and Dr. R. G. Hopkinson also of the BRS and a vice-president of the IES. Mr. J. Longmore of the BRS and Mr. H. Bellchambers also assisted.

The course was opened by Mr. Allen and Mr. Medd, both architects, who summarised the lighting problems, Mr. Allen from the general point of view and Mr. Medd in relation to the design of a new type of primary school for which he and his colleagues from the Ministry of Education had been responsible. Mr. Allen emphasised that there had been a major change in lighting policy since the war. Before the war lighting was essentially computational but there had been no study of people or how they were affected by lighting. He believed that the impression made by an environment depended more on the eyes than on any other sensory process. People can be induced to have certain feelings: they will, for example, say "how gloomy this room is." We are now beginning to know how these impressions are produced and we know that colour and light in a building control and influence feelings of well being, happiness, or depression. It is part of the designer's business, whether he likes it or not, to create an environment which influences these feelings; if he does not understand how they are produced he will only fumble in his design. He must be helped to create what he wants and one of the objects of the course was to show how far recent technical developments have enabled these matters to be rationalised.

Light and Colour in Schools

Mr. Allen mentioned the impact of the new designs of schools in Hertfordshire where light and colour had played a great part. He described how in the first of these schools the teachers considered that the light environment was responsible for the remarkable change in the attitude of the children, their attentiveness and freshness, which made teaching easier. The teachers attributed this change to the lighting—and not to the ventilation as had been suggested. Mr. Allen went on to describe his views on the main principles of good lighting; the object of attention should be the brightest for we then see better; there should be a gradual control of contrast for comfort, and the light sources themselves should be graded for comfort.

Mr. Medd said that the lessons to be learnt in the lighting and colour of a school could be applied to other buildings if the principles are sound. For that reason he confined his remarks to the school lighting problem knowing that others could amplify them in relation to other buildings where necessary. He described how in the initial work on the Amersham school he discussed the educational problem in a junior school with a large number of teachers. He obtained a clear idea of the educational requirements and knew to what extent they could be applied within his financial limitations. It was important not to be revolutionary because the more conservative teacher had to be able to work in the environment as well as the more progressive. One could only hope that the environment would be a challenge to the more conservative. He demonstrated with a number of slides common faults in school buildings, and pointed out that in the teaching of children from the ages of seven to eleven a great deal that is taught in secondary schools has also to be taught first in the junior school. The teaching requirements are therefore very complicated. He believed that different units to reflect different ages and interests are necessary. His plan was therefore to have four pairs of classrooms grouped round a central courtyard, each classroom having its own little units in which different types of work could be done. It was fundamental that children should be able to see out of the room and experience the different aspects of the clouds and the sun. He therefore planned rooms with a number of bays in such a way that they acted as devices to lead light gently into the centre of the room. Such a design posed a number of lighting problems. First, the efficiency of the windows, that is to say the glass area related to the total opening, had to be high, and careful design of the glazing bars permitted a window efficiency of the order of 73 per cent. Second, the ceiling had to be as light as possible and the floor also very light (of the order 30-40 per cent. reflection factor). The walls had to be well lit and their reflection factors (which should not be the same for all walls) sufficient to enable them to redistribute light where necessary. Mr. Medd described the artificial lighting of the school, the main novel feature of which was the provision of small local lights with highly specular exteriors to give "sparkle."

Principles of Good Lighting

The following morning Dr. Hopkinson opened with a description of the subjective studies on lighting made at the BRS. He showed how the brightness of the environment was at least as important as the lighting levels in the determination of good lighting, whether by artificial or by natural means. The adaptation mechanism of the eye was such that the appreciation of lighting level was governed very much by the general lighting conditions in the field of view. He demonstrated how the brightness as it appears to the beholder is determined not only by the brightness of the object itself, but also by the brightness of its surroundings. The lighting levels in a simple environment can be determined readily by the IES Code and he urged architects to have copies of the Code available in their schools and to teach its use to students. The problems of glare were discussed and demonstrations to show the difference between glare which causes disability and glare which causes discomfort were shown. Dr. Hopkinson summed up his thesis by suggesting ten principles of good lighting.

(1) We see better the more light we have. Simple lighting tasks demand about 10 lm/ft^2, more difficult ones about 50 lm/ft^2, and improvement continues even beyond this level.

(2) We see better if the main visual task is distinguished from its surroundings by being brighter, or more contrasting, or more colourful, or all three.

(3) We see better if the things we have to look at are seen in an unobtrusive and unconfusing setting. Good lighting demands a moderately comfortable level of general lighting with preference for lighting on the work. (Dr. Hopkinson called this lighting system "focal" lighting.)

(4) The surroundings should be moderately bright, and

this should be achieved by a combination of lighting and colour treatment.
(5) No source of light should be a source of glare discomfort. The lighting should be designed to prevent excessively bright areas being visible.
(6) Plenty of light should reach the ceiling and the distribution brightness in the room should dispel any feeling of gloom.
(7) Sources of light should be chosen to ensure that the colour rendering which they give is satisfactory in the situation in which they will be found.
(8) Care should be taken to eliminate any discomfort from any flickering light source.
(9) Dull uniformity should be avoided. Shadowless lighting is rarely necessary and never stimulating. Small brilliant points of light can give sparkle to a scene without causing glare. (Mr. Medd's specular surface fittings were instanced as an example of how this could be done.)
(10) The lighting in a building should always be considered in relation to its design. The whole environment determined a good lighting installation.

Dr. Hopkinson then went on to discuss the application of these principles of lighting design showing how the development of a scheme ended in a specification in terms of sources (windows or artificial lighting) and of surfaces. Surfaces could be specified either as reflection factors, or through translation through the Munsell Value scale into a specification of colour lightness. Up to this point the design of lighting is a collaboration between the architect and the lighting engineer, with the lighting engineer playing the major part. Beyond this point the architect was on his own, because, in Dr. Hopkinson's opinion, the colour of an installation was chiefly a matter of aesthetics at the moment and should be handled by the architect.

Mr. Medd and Mr. Allen then took over and described the basis of the new British Specification for colour in buildings (BS2660). This standard had been based to a large extent on photometric studies of natural lighting which in turn derived from the concept of Munsell Value. It was proving a valuable tool in the collaboration between the architect and lighting engineer.

Light Sources and their Application

On Friday afternoon Mr. Dykes Brown described light sources and their applications. He gave a résumé of the types of lamp now available and of their more important characteristics. He emphasised that the different types of lamp were complementary and not competing with one another; each type of lamp performed a certain task and the competent lighting engineer knew how to specify which source was necessary in any given situation. Mr. Dykes Brown agreed that it was unfortunate that there were so many different types of hot cathode fluorescent lamps but believed that the new warm white and de luxe warm white would together fulfil most needs. He described the characteristics of these lamps in some detail. As regards cold cathode lighting, it had a great many advantages when used in the proper situation. In spite of the fact that it had to work on a high voltage it was quite safe when installed by a competent engineer. The agreed lamp life was now 25,000 hours although, in fact, installations had been functioning longer than this. One installation had been functioning for 42,000 hours and the efficiency of this installation had dropped from 28 lm/w initially to a value of 22 lm/w, a reduction which made the installation still economic to run. Mr. Dykes Brown dealt briefly with the economics of lighting, but emphasised that it was impossible to generalise as so many important factors (e.g., labour charges, cost of electrical energy) differed from one installation to another. He pointed out that maintenance was important because a clean-up on an installation could raise the illumination level and rejuvenate the installation; it is often cheaper to replace lamps when cleaning than to replace individual failures, and suitable equipment for maintenance is necessary especially in industrial locations, and he showed some illustrations of factory schemes in which the equipment for maintaining the lighting had been built into the design of the factory. The rest of the lecture was taken up with a series of interesting lantern slides showing recent lighting installations employing a wide variety of lighting methods.

Daylighting

The rest of the Friday session was devoted to a discussion on natural lighting and its computation. Mr. Allen emphasised that the advantage of teaching architectural students to use the BRS Protractors was that it made them realise that daylighting was a geometrical problem. Too many students seemed to think that light flowed into a building just like air—they probably thought this because there was usually a high amount of reflected light in a building. He suggested that architectural students should be taught how to develop the shape of sky factor contours and to recognise their systematic and indiviudal appearance with different window shapes. The student should in fact get a picture of these shapes in his mind's eye because without this he could not visualise how light would be distributed from a window pattern.

Lighting Design

The following morning Mr. Wilcock gave a summary of the design technique used by the practising lighting engineer. He emphasised that these simple techniques were merely the basis of the lighting engineer's work because a good lighting installation was planned by experience and skill as well as by calculation. A good lighting engineer always visited a building which he had to light in order to get an idea of its possibilities. Working from the plan of a building is often unsatisfactory. If the building does not already exist the architect would serve the lighting engineer much better by preparing proper perspectives in the way which Mr. Medd had done for his Amersham school. The lighting engineer can then get the feel of a building from a look and he can assess reflection factors in terms of their appearance. Having determined the tasks necessary in the building, the IES Code gives him the illumination levels and he can think in terms of fittings and illuminant guided by the client or the architect. Mr. Wilcock urged lighting engineers and architects not to choose fittings from a catalogue but to visit the showrooms and see the fittings lit up, if possible in a complete installation. After describing the Harrison-Anderson method of calculation and the simple statement of it in the ELMA Lighting Handbook No. 2, he went on to describe a more recent approach to the subject made by the National Illumination Sub-Committee on Lighting Principles under the heading "The Design of the Visual Field," and the development of the method by Mr. Waldram. Mr. Wilcock outlined Waldram's approach as applied to the lighting of a church. In the course of discussion, Mr. H. E. Bellchambers described his own method for the computation of room brightnesses, saying that he had found it difficult to apply the apparent brightness data in the way which Mr. Waldram recommended, although the concepts of apparent brightness was one which he found useful. His approach has been in fact more along the lines of the BRS work on natural lighting, but applied to artificial lighting. He demonstrated his work with a model.

In the evening Dr. Hopkinson introduced by means of a film the techniques being used to study lighting installations with the use of models. Recent methods enabled models to be built very simply and quickly both for artificial and natural lighting studies. In this way photometric information would be obtained at least as quickly as by calculation, and in addition valuable subjective information unobtainable by any other means resulted from careful inspection of the model. A lively discussion followed this exposition in which it was generally agreed that models had an unassailable place in the study of natural lighting, but owing to various engineering difficulties, might not be so suitable for the study of artificial lighting. Dr. Hopkinson disagreed and instanced Mr. Bellchamber's work and his own on the studying of the artificial lighting of hospitals and school classrooms. Mr. Allen said that architectural schools would be much more ready to make model studies of artificial lighting if the lamp manufacturers would let them have lamps and fittings to a miniature scale suitable

for models. Dr. Hopkinson emphasised that he used standard products, and Mr. Bellchambers agreed that sometimes he found it valuable to get special lamps made for his studies. He suggested that the architect who wanted to make studies of this kind could always approach a sympathetic lamp manufacturer and it was quite likely that something could be done for him.

The session was completed by a discussion by Mr. Medd and Dr. Hopkinson of the calculation of daylight. Mr. Medd stressed that the quantity was not all-important. The architect has to get the business of calculation into proper perspective in relation to the whole design problem. He urged architects not to fall in love with calculating tools just because they had learned to use them. They should use their imagination; it is a prerogative of the architect to do so, and he must not be a slave to his tools. Nevertheless techniques should be mastered in order to be applied. He outlined the methods for the calculation of sky factor and stressed the importance of making proper allowance for the obstruction caused by glazing bars on windows. The agreement between computation methods and the finished result was now very good. Dr. Hopkinson described the recent work of the BRS for the computation of reflected light and the simplified inter-reflection formulae which were in use there. He illustrated his talk with the BRS monograms and Daylight Factor Slide Rule and mentioned in passing that the same technique could be used and had in fact been used at the BRS for some time for the computation of artificial lighting.

During the afternoon Mr. Derek Phillips gave a detailed exposition of artificial lighting in relation to architectural design. A highlight of the discussion was a form of ceiling lighting which Mr. Phillips has developed. He described the use of plastics in lighting design and showed the range of materials generally available and the purposes for which each were suitable. The talk was illustrated by numerous lantern illustrations of installations in Europe and America.

The Lighting Industry

The Saturday evening session and the following sessions on Sunday were all occupied in general discussion. During this Mr. Dykes Brown described the set-up of the lighting industry. Lighting was a subject which was developing so fast, said Mr. Dykes Brown, that the independent consultant was very often out of date simply because he could not keep up with the changes in technique resulting from the latest research by the leading manufacturers. He urged those in touch with students to make sure that they were told how to get proper advice on lighting matters. Since the war a number of firms had sprung up who supplied lighting but knew practically nothing about the subject. Sometimes an architect would get a reputable lighting firm to submit a lighting scheme, but owing to the cost of the scheme would have it implemented by an organisation offering material at a lower price. Such an organisation would probably have no technical man on its staff and would not understand the principles behind the scheme submitted by the original firm. The result was that the installation, when complete was obviously unsatisfactory. Mr. Dykes Brown said that all lighting engineers would welcome a stronger brief from the architect. Too often the architect was vague and uncertain about his requirements. One of the values of Mr. Waldram's work was that it demanded precision from the architect in his briefing of the lighting engineer. It would take a long time to transform a primarily engineering profession into a design profession, and in the meantime the architect must appreciate the engineers' limitations and also respect his strength. Mr. Derek Phillips emphasised that there was no benefit from joint consultation of architect and engineer if they were unable to speak the same language, and a great deal needed to be done in the sphere of mutual education. Mr. Wilcock summed up the functions of the Illuminating Engineering Society and distinguished them from the services which could be rendered to architects by the Lighting Service Bureau. He urged architectural teachers to join the IES themselves and to encourage students to do so.

York Art Gallery

On Saturday evening a party visited the new fluorescent lighting at Beverley Minster, and on Sunday morning an inspection was made of the City Art Gallery of York in preparation for the afternoon session at which the lighting requirements of the Art Gallery were discussed. The Director of the Gallery, Mr. Hans Hesse, asked that the discussion should take it as a principle that no fluorescent lighting would be used. He wished the lighting to be from tungsten filament lamps because he believed that their colour was more suitable for paintings which in their original form had been viewed either by daylight or by candle light. A full discussion of the lighting problems then followed in which many of the course members made valuable contributions. At the end of the session Dr. Hopkinson asked Mr. Hesse if he would now specify his reasons for his prejudice against fluorescent lighting. Mr. Hesse said he believed that in fluorescent lighting there was something essentially wrong; colours were not modified equally but harmonies were distorted, textures were changed into something harsh and metallic looking, the lighting was almost shadowless and was consequently unnatural. Mr. Hesse believed, or at least had a suspicion, that the physical presence of fluorescent lighting was not conducive to happiness: it was an irritant and not a healthy thing to have in a room, it gave the effect of a concentration camp with a constant supervising glare. Pictures should be seen in their natural surroundings and not submitted to the glaring light of an operating table. If he could, he would light his gallery by candle light; the nearest to this was well-designed filament lighting.

Mr. Hesse's remarks about fluorescent lighting gave rise to a lively discussion in which both Mr. Bellchambers and Mr. Dykes Brown insisted that Mr. Hesse must have had his prejudices developed as a result of having seen so much bad fluorescent lighting. Mr. Dykes Brown instanced at least one Art Gallery (Amsterdam) where highly skilled lighting of a well-known picture had been done in such a way that nobody was aware that fluorescent lamps were used. He doubted whether Mr. Hesse himself would have detected this.

The course ended with a session in which members collected together the particulars of slides which had been shown at the meeting to build up a library for their own lectures to students. It was generally agreed that the course had served a very useful purpose, and the lecturers equally felt that they had gained as much pleasure as they had given.

Forthcoming Conferences

Association Francaise des Eclairagistes

The next Journess de l'Eclairage of the French IES will take place in Reims from April 24 to 26. The technical sessions will deal with lighting education, street lighting, signal lighting and colour and lighting in industry. As with previous similar meetings of the AFE the opportunity will be taken to arrange full-scale demonstrations of modern street lighting and floodlighting. Full details will be available in due course from the General Secretary, Association Francaise des Eclairagistes, 33, Rue de Naples, Paris 8.

Lichttechnische Gesellschaft e.V.

The German Illuminating Engineering Society will hold its next annual meeting in Mannheim from March 19 to 22, 1958. Following an inaugural discourse, "A Peep Behind the Scenes," in the new Mannheim National Theatre, some 20 technical papers are planned for presentation on the following subjects: The present position with regard to electroluminescence, Modern cine projection, Lighting problems in television, Light in plant cultivation, Plastics in lighting, New illuminating glasses and their artistic design, Evaluation of daylight, The present position with regard to the evaluation of glare, Problems of traffic lighting. A social evening with entertainments and a number of excursions are also planned. Individual invitations, with a detailed programme, will be issued in due course.

NEW PRODUCTS

Trunking

Crompton Parkinson Ltd. announce the introduction of their "New-Line" lighting trunking which has design features enabling it to be installed rapidly, securely and rigidly, with maximum suspension centres and continuously variable positioning of many types of lighting fittings. A heavy gauge rolled steel channel is used in which the folds, besides aiding the rigidity and strength characteristics, also provide useful functions as mounting and clamping surfaces, for the securing-clamps and fittings. It is supplied in lengths of 15 ft., 9 ft., or 6 ft. and coupled by a simple internal coupling which automatically eliminates any sagging or twisting at the joints and gives definite longitudinal alignment. During erection the only tool required is a screwdriver. The trunking is secured to the roof truss or ceiling by the use of robust stirrup clamps inserted into "vee" folds at any point along the length of the trunking. Factory wired lighting fittings are secured to the trunking with a minimum of installation work. The line wiring is supported on insulating bridges and ample room is allowed for mains and switch circuits. A simple but effective line tap enables the position of fittings to be readily changed, or alternatively allows local control pull switches or pilot lighting to be inserted with the aid of a clip-on plate without any major disruption of the system. Plastic covering, manufactured in 5 ft. 6 in. lengths and cut to required size, snaps over the bottom of the trunking thereby providing an attractive protective closure.

The "New-Line" trunking allows fluorescent, filament or discharge lighting fittings to be installed. Changes to an existing system when additional facilities are required may be made cheaply on standardised components. The trunking is designed to have a useful life comparable with that of a modern building.

Street lighting columns

Stewarts and Lloyds Ltd. have four new designs of 25-ft. tubular steel street lighting columns for Group A lighting.

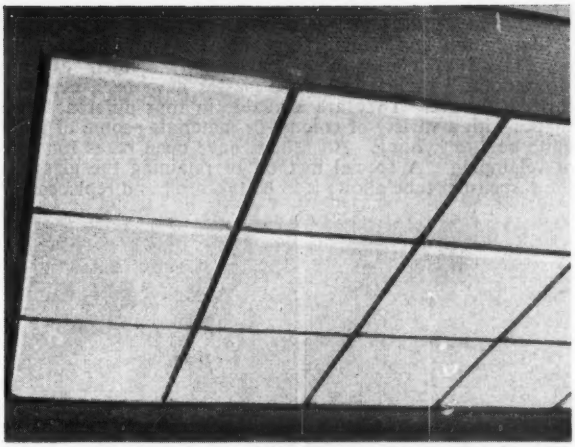
In all four designs, the base tube diameter is $7\frac{5}{8}$ in. with a door opening $5\frac{1}{2}$ in. wide. The shaft is only $4\frac{1}{2}$ in. diameter. The new designs may have either straight or curved bracket arms up to 7 ft. 6 in. outreach and these can be supplied for use with either pendant or side-entry lanterns whose weight is in the region of 25 to 30 lb. and whose wind area does not exceed 2 sq. ft. The designs have been approved by the Council of Industrial Design.

Projection lamp

Philips Electrical Ltd. have introduced a new type of projector lamp for use with 8 mm. projectors. Known as Type 13113C/O1, it is an 8v 50-watt lamp with an elliptical mirror incorporated in the bulb. The carefully controlled filament is of small dimensions and is located at the principal focus of the mirror. When the lamp is used with an 8-mm. projector, the secondary focus of the mirror occurs in the position of the gate, so that an image of the filament is produced on the gate area. The screen illumination is claimed to be at least the equivalent of a 500-watt lamp in a conventional projector, but as this is achieved with only one-tenth of the wattage, there is, therefore, approximately only one-tenth of the heat. Further, the use of this new lamp makes possible a great improvement in optical efficiency of 8-mm. cine projectors. List price is £1 15s.

Modular lighting ceiling

A flexible lighting system (known as the Lumenator Module) which can be used either to provide overall illumination or to highlight particular points is now being produced by Lumenated Ceilings Ltd. It consists of a false ceiling of translucent plastic panels supported in an aluminium framework suspended below the lamps which are fixed to the structural ceiling. The layout is based on a 2-ft. square module.



Close up of the Lumenator Module system. In this instance plain acrylic panels are used.

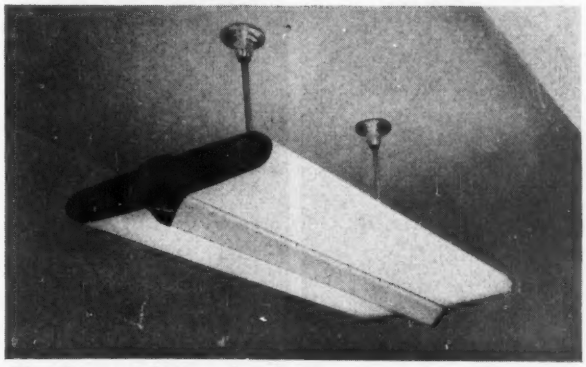
The translucent panels diffuse the light evenly without glare, high spots or shadows, and they are claimed to look attractive even when the lights are switched off. Two standard panels are available; one is moulded from vinyl plastic, in which decorative features may be incorporated; the other is moulded from acrylic plastic. It is understood that the panels will in due course be available in colour.

The panels are each 2-ft. square and rest on an aluminium framework suspended from the structural ceiling. They can be lifted out by hand for cleaning or to provide access to the lamps or other services located in the plenum. The extruded aluminium track has a fluted face and is supplied, with the ends already accurately mitred, in standard lengths of two, four, six and eight feet. Slide-onclips are used to join lengths together. The framework can be anodised if required. A wide variety of layouts can be achieved by incorporating 2-ft. square panels of hardboard, acoustic tiles, etc., in combination with the diffusing panels.

The cost of the Lumenator Module system is comparable with the cost of the Lumenated Ceiling system, which is approximately 10s. per square ft. (excluding lamps) for a large installation. The system has been accepted by the Council of Industrial Design for inclusion in "Design Review."

Pendant fluorescent fitting

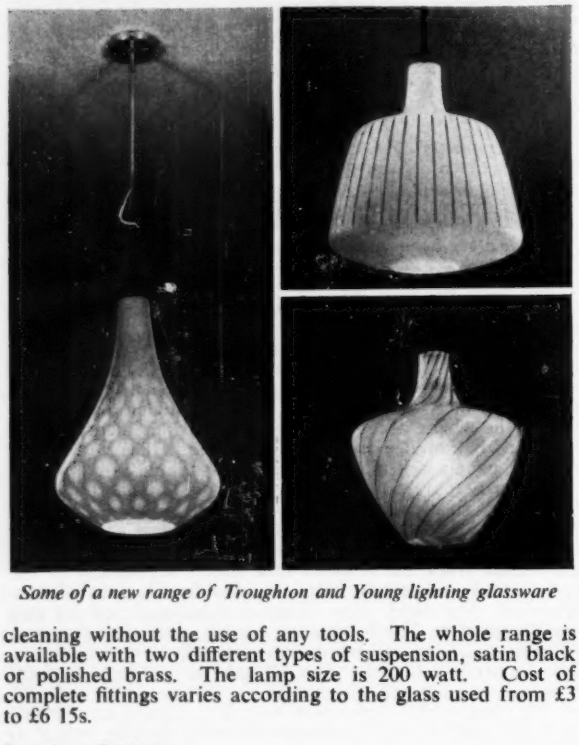
Ekco-Ensign Electric Ltd. have recently introduced a new pendant fluorescent fitting designed principally for commercial interiors but also suitable for domestic use. The fitting is available in three sizes, each of which uses four 5-ft. 80-watt or 4-ft. 40-watt or 2-ft. 20-watt fluorescent lamps. The plastic end plates are available in a variety of colours.



Ekco fluorescent lamp pendant fitting.

Lighting glassware

Troughton and Young (Lighting) Ltd. have designed a new range of glasses as an extension to their existing "Mondolite" range. All these glasses have been designed for general use. They are available in four different basic shapes with a variety of colours or materials—some of them quite new to lighting. All fittings have open bases for ease of relamping. A special method of retaining the glass on the suspension tube allows it to be taken off and replaced for

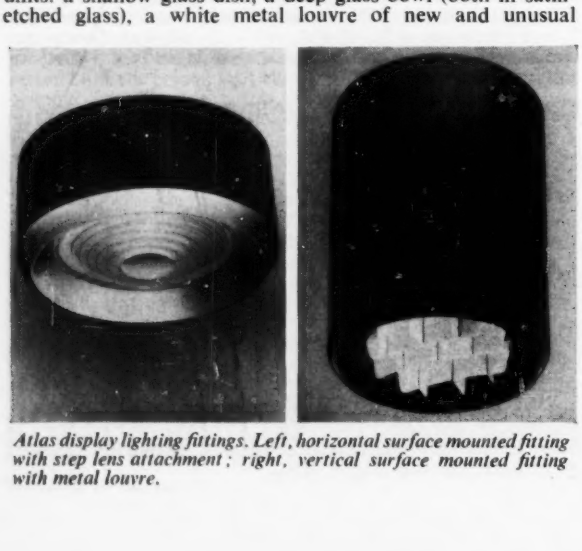


Some of a new range of Troughton and Young lighting glassware

cleaning without the use of any tools. The whole range is available with two different types of suspension, satin black or polished brass. The lamp size is 200 watt. Cost of complete fittings varies according to the glass used from £3 to £6 15s.

Display fittings

A new range of incandescent lamp display lighting fittings has been introduced by Atlas Lighting Ltd. The range is based on a series of interchangeable components and comprises four basic units for horizontal and vertical flush or surface mounting, in different sizes to take lamps from 60-300 watts. There are five types of attachment for these basic units: a shallow glass dish, a deep glass bowl (both in satin-etched glass), a white metal louvre of new and unusual



Atlas display lighting fittings. Left, horizontal surface mounted fitting with step lens attachment; right, vertical surface mounted fitting with metal louvre.

design, a clear stepped lens and a sheet glass diffuser in "Festival" glass. Colour filters are also available. A neat lock-on soffit ring completely hides fixing screws and secures the attachment to the fittings. Four types of finish are used for the ring—gun metal, citron, flame and an anodised gold finish. Over 50 different combinations are thus possible and the range is augmented by a number of speciality units.

Trade Notes

Atlas Convention

The 1957 Atlas Lighting Convention which opened at St. Pancras Town Hall in London on September 26 has since visited Bristol, Sutton Coldfield, Manchester, Glasgow, Whitley Bay and Harrogate. In each town the audience has been between 450 and 750. Although this annual convention was first inaugurated only last year it has already a reputation for being a light-hearted but well-informed way of presenting the company's products and services to its customers. This year maintained the standard created at the first convention. It was opened by J. G. Christopher, Director and General Sales Manager, who followed his cordial welcome by mentioning the formation of Atlas Lighting, Ltd., as a subsidiary company to deal solely with the lighting activities of Thorn Electrical Industries, Ltd. He also spoke of the success of the "Atlas Popular Pack"; in October the 500,000th pack was assembled at Spennymoor and the buyer will be presented with a Ferguson "Fantasia II" radiogramophone. Dr. H. H. Ballin, Director and Technical Sales Manager, gave a lecture explaining, with the aid of short films, what is meant by the eight-way electronic testing of Atlas lamps. This was followed by a 25-minute film entitled "Fitting Conclusions" which showed the manufacture of control gear, starter switches and lamps and demonstrated various applications of fluorescent lighting fittings.

The final item of the convention was a two-act play, written, produced and acted by members of the company to show the latest lighting fittings and the services that are offered to customers. By using topical and amusing conversation throughout the play to link up the events which must be daily occurrences in any typical showroom it was lively and interesting entertainment. The finale highly amused all audiences, especially those who had visited the "Son et Lumière" productions this summer; Atlas Lighting, Ltd., presented their own stage version of "The Story of Barnacle Folly," a whimsical demonstration of typical light and sound effects.

Lighting Council

As previously announced the work of the Lighting Service Bureau is to be expanded under the auspices of a new governing body whose founder members are: The British Electrical Development Association, The Electric Lamp Industry Council, and The Lighting Equipment Development Council.

At a meeting of the Council of Management of this newly formed body on Wednesday, October 30, the following officers were elected: Chairman, D. Bellamy, O.B.E. (B.E.D.A.); Vice-chairmen, W. T. Souter (L.E.D.C.), A. E. Page (E.L.I.C.); Members of Council (representing B.E.D.A.), J. I. Bernard, W. N. C. Clinch, D. B. Irving, W. S. Lewis, W. B. Noddings; (representing E.L.I.C.), J. G. Christopher, J. Clement, W. J. Jones, C. J. W. Scott, H. C. White; (representing L.E.D.C.), H. H. Ballin, J. H. Campion, T. S. Jones, F. W. Norris, A. H. Young. The secretary is E. B. Sawyer.

Pending the acquisition of larger premises in a central position, the Lighting Service Bureau will continue to operate from its present address at Savoy Hill and through its Area Engineers in Birmingham, Glasgow, Leeds, Manchester and Newcastle.

Licht-Decken G.m.b.H.

Lumenated Ceilings, Ltd. (Alliance House, Caxton Street, London. S.W.1), has formed a subsidiary company in Germany. The head office of the company, Licht-Decken G.m.b.H., is at 123 Hansaring, Cologne. The managing director is Mr. M. K. Hansen who was formerly in charge of the luminous ceiling department of the German representatives of the General Electric Company. Among the reasons

for forming the company must be counted the possibility of the European Common Market, and the even greater opportunities which would then exist to promote the products of the parent company.

Trade Literature

ATLAS LIGHTING, LTD., 233, Shaftesbury Avenue, London, W.C.2.—A new catalogue of incandescent, fluorescent and discharge lamps, fittings and accessories in the form of a comprehensive technical guide in the use of Atlas lamps and equipment. Full technical details on different types of lamps are given, including such matters as colour appearance and colour rendering of fluorescent lamps. Details given on fittings include polar curves, dimensions, coefficients of utilisation, light output ratios, cut-off angles, minimum recommended mounting heights, etc.

J. A. CRABTREE AND CO., LTD., Lincoln Works, Walsall, Staffs.—Brochure No. 1190 describing this company's recent introductions in wiring accessories, including switches, lug boxes and pattress blocks, together with current prices.

CRYSELCO, LTD., Kempston Works, Bedford.—Several new leaflets giving details and prices of the following products:—commercial and home fittings, slimline channel fittings, opal glassware, electric discharge lamps and industrial fluorescent fittings

H. W. FIELD AND SON, LTD., Harold Wood, Essex.—Leaflet giving details and prices of the "Spot-On" fluorescent lighting fitting.

G.M.B. (ELECTRICAL) BIRMINGHAM, 439, Moseley Road, Birmingham 12.—New catalogue with separate price list describing fully modern and traditional lighting fittings for domestic and industrial use as well as electrical heating products.

HOLOPHANE, LTD., Elverton Street, London, S.W.1.—Publication S.L. 957 dealing with a new street lighting unit for Group A roads. This is the new Oval Bowl lantern for use with 250- and 400-watt fluorescent bulb (colour-corrected) Type MBF/U lamps and mercury discharge Type MA/U lamps.

Situations

Vacant

DESIGN/DRAUGHTSMAN required to take charge of a Section engaged on the Design and Development of Lighting Equipment. Experience of this work preferred but not essential. This is a Senior position and applicants must be capable of carrying projects through to production stage. The vacancy carries excellent prospects with a competitive salary according to age, experience and qualifications. Staff Pension and Bonus Schemes. Apply in writing, giving full particulars, to the Personnel Manager, Siemens Edison Swan Ltd., 38-39, Upper Thames Street, London, E.C.4.

DESIGN/DRAUGHTSMAN capable of working with minimum supervision and developing original ideas. Experience of lighting equipment preferred but not essential. This vacancy carries a competitive salary according to experience, age and qualifications. Staff Luncheon Room, Bonus and Pension Schemes. Apply giving full particulars, quoting Ref. O.24, to Box No. 936.

LIGHTING ENGINEER with planning and contact experience required for Manchester office of Ekco-Ensign Electric Ltd. Apply Manager, Blackett Street, Fairfield Street, Manchester, 12.

YOUNG MAN, completed National Service, required for Illuminating Engineering Dept. of Ekco-Ensign Electric Ltd. The applicant should be well educated and previous knowledge and experience in modern lighting methods would be preferred. Apply Senior Lighting Engineer, 45, Essex Street, London, W.C.2.

VERITYS LTD. have a vacancy for a LIGHTING ENGINEERING ASSISTANT. Keen young man with experience in layout of lighting schemes. Superannuation and bonus schemes in operation. Apply stating previous experience to our Works—Plume St., Aston, Birmingham 6.

Book Reviews

"Generation, Transmission and Utilisation of Electrical Power," by A. T. Starr. Fourth edition. Pp. xi + 529; Figs. 431; Index. Published by Sir Isaac Pitman and Sons, Ltd., London, 1957. Price 27s. 6d.

This book is one of the well-known "Engineering Degree Series" and was first written in 1937 for the student studying for an engineering degree or an examination of similar standard. It deals with that part of the syllabus described by some such title as "Electrical Power," so that the ground covered is very extensive. In this new edition the author has added a short treatment of the subject of generation by the use of nuclear energy.

The chapter headed "Illumination" contains only 31 pages and is a curious mixture of the up-to-date with the completely obsolete. The most striking example of the latter is the reference to the pentane lamp as providing "the British standard of candle-power." There are a number of other places where the text needs revision in order to bring it into accord with present practice. For example the relative luminous efficiency factor (called by the author the relative luminosity factor) is denoted by $K\lambda$ instead of $V\lambda$, which is confusing because $K\lambda$ has a different, though related, meaning. On another page there is a clear suggestion that the tungsten arc lamp is suitable for indoor lighting. On the other hand, the descriptions of the filament lamp and of the sodium and mercury discharge lamps are satisfactory considering the very limited space devoted to the whole subject.

The book is not intended for the student of illuminating engineering; for the student of electrical engineering who wants a concise treatment of the very wide range of matters indicated by the title, it will no doubt continue to serve as a very useful text-book. J. W. T. W.

"Electrical Discharges in Gases," by F. M. Penning. Pp. viii + 75; Figs. 29; Index. Philips Technical Library. Published by Cleaver-Hume Press, Ltd., London, 1957. Price 15s.

In spite of the long time which has elapsed since the different forms of electrical discharges in gases were first described, and the great importance they now have in practical light sources, the phenomena are so complex that probably most lighting engineers would confess that the subject is one about which they know comparatively little. Dr. Penning's book is a useful brief synopsis, cast in the form of a series of essays, which has now been made available in the English language. The translation is excellent and the short bibliography at the end of the volume, selected with care and discrimination, should make the book especially valuable to those who want a reliable guide to the study of the subject. At the same time it should be mentioned that, in covering a good deal of ground within a comparatively few pages, the author has necessarily written concisely and the book demands careful attention from the reader, especially if he does not already possess some background knowledge in this field. The production is commendable and there are comparatively few printer's errors. J. W. T. W.

Miscellany

Machinery Wanted

Inter-Continental Exports and Imports, 522, Diagonal Road, Visvesvarapuram, Bangalore-4, S. India, are interested in the purchase of all kinds of secondhand or reconditioned lamp-making machinery (miniature, G.L.S., hot and cold cathode fluorescent) both as separate machines or complete sets of machines.

Frontispiece

The chandeliers shown in the frontispiece on page 373 were made by Glassexport of Prague.

'Light and Lighting'

Some of the issues of *Light and Lighting* during the past year are out of print but copies can still be supplied of the majority, including the March issue in which the main feature was cinema lighting, and the August issue which contained the article by Dr. Dresler on Inter-reflections.

I.E.S. ACTIVITIES

London

At the sessional meeting held at the Science Museum, South Kensington, on November 12, a paper entitled "Artificial Lighting as Applied to Museums and Art Galleries" was presented by W. E. Rawson-Bottom and J. B. Harris.

Museum and art gallery lighting has evolved during the past 100 years. Research has revealed that the pioneer work was remarkable for the appreciation of the problems involved and for the ingenuity displayed in their solution. A brief review of the historical background provided an interesting introduction to this paper. Since those early beginnings this particular application of artificial light has seen many changes, but for some 25 years at the beginning of the century, little development was evident. An impetus was given just after the First World War by the introduction of gas-filled lamps. These made the optical control of light a possibility, enabling a comparatively large area of wall surface to be illuminated from a single source. In those days it was considered an achievement to provide a value of 3 to 4 lm/ft². This low value of illumination coupled with the indifferent colour rendering obtainable was insufficient to reveal the subtleties of colour and texture which for the true appreciation of art is essential.

During the last decade the research and development that has gone into finding the ideal solution to the problem of art gallery lighting has been considerable and some good results have emerged. One example is the lighting of the new air-conditioned rooms in the National Gallery, where the artificial lighting has been successfully merged with the architectural features. It has been said of this scheme that the appearance of these rooms and pictures at night is comparable to daylight. The method employed there may well set a standard in design for the future.

Museum lighting has also been the subject of much development, especially during recent years, not only to keep pace with the increase in illumination that is being demanded generally, but because museum authorities now appreciate the value of this essential aid to display. Here again it was the introduction of a new light source that made some of the present-day museum lighting possible. Internal lighting of showcases, for example, was not a practical proposition until the fluorescent lamp came into being. It is now usual for modern showcases to be designed to accommodate internal lighting suitable for the particular exhibits they are to contain. Even with the comparatively cool running of these lamps, heating problems do occur though these can now be largely overcome by incorporating a ventilation system which does not affect the exhibits. Background colours in showcases play their part in setting off a display and can be regarded as a part of the lighting scheme. The general lighting of exhibition areas also has been vastly improved by the gradual improvement in light sources and the lighting fittings to contain them.

Birmingham Centre

The second meeting of the Birmingham Centre during the present session took place on October 25, when a paper on "Horticultural Lighting" was read by Mr. W. A. Gray, of the Agricultural Advisory Section of the Central Electricity Authority. The main part of the paper was the effect of different light sources on various forms of plant life and the uses to which they could be put. Mr. Gray described how plants responded to light, and the duration of exposure required for a desired result. He dealt with the effects of long nights and short days on plant life and growth, going into the question of colour control and colour response, daylight and intensity control, and described the effects of blue light and red light on plants. He spoke of photo-periodic response which controls the life of the plant from beginning to its end, and photosynthesis which controlled bulk growths.

Mr. Gray described experiments carried out in Holland with pure blue light and blue light with a little red included. He said that so far there was no instrument for measuring plant response to light, or the amount or intensity of light a particular plant might require. He went into the use of tungsten lamps where long growth was required.

A most interesting discussion was opened by Mr. Martin Harvey, and in his reply to numerous questions, Mr. Gray described effects of light sources on potatoes, apples, lettuces, plant group response, and plant forcing rooms.

Manchester Centre

On October 17 nearly 100 members and visitors heard Mr. F. P. Bentham's talk on "The Stage and the Lighting Engineer" to the Manchester Centre.

Mr. Bentham explained the necessity of the compact source lamp, but regretted that in his opinion this country was lagging behind the United States in the development of this type of lamp. It was conceded that there had been rapid strides in the development of low brightness discharge lamps, low brightness fluorescent lamps and tungsten lamps, but none of these covered the needs of the staple equipment of stage lighting.

In discussing stage lanterns Mr. Bentham said that these consisted of spotlights with adjustable beams and floodlights, the latter usually fitted with hoods to control the cut-off and avoid low intensity stray light. Spotlights took three forms: (a) Focus lanterns, a simple lens behind which was a movable lamp; (b) Fresnel spots with a short focus; (c) Profile or mirror spots in which light is collected by a mirror and directed through an adjustable gate, the shape of which is focused by a lens.

Colour filters could be used in front of all lanterns, but colour should be used with discretion, especially in straight drama. Effects should be obtained by the positioning of lanterns and directing their beams.

By a series of coloured slides the principles of lantern placing were demonstrated—particularly the need to cross the light beams and place the lanterns in a high position. Mr. Bentham emphasised that the lighting on stage should be directed mainly from the side and towards the opposite side of the stage, and a most effective position was at the sides of the auditorium with beam centre lines making an angle of approximately 45 deg. vertically and horizontally with the centre line of the stage.

Mr. Bentham then demonstrated with coloured slides correct and incorrect stage lighting and the correct use of spots. By the correct use of spotlights emphasis could be directed to the positions required by the action, and the time of day (early morning, afternoon, evening and night) could be clearly indicated.

The several deliberately controversial points which Mr. Bentham raised led to a lively discussion, which ended only when the chairman decided that the meeting must close.

The annual dinner of the Manchester Centre was held on November 6th. The principal guest was the Lord Mayor of Manchester who replied to the toast, "The City and Ports of Manchetser" which was proposed by the chairman of the Centre, Mr. P. Corry. Mr. Corry said he thought the City of Manchester was important enough on its own without the need for associating the ports with it in the toast; if

ports had to be included then why not also include other services such as the railways—though, he added, a little toasting might on occasions be a good thing.

The toast of the Society was proposed by Mr. R. H. Hammans, Chief Engineer of the Granada TV Network. In reply, the president, Mr. E. B. Sawyer, spoke of the great value of the voluntary efforts of the officers of the various Centres and asked all members to do their utmost to increase the membership of the Society which he said had much to offer those who were concerned with lighting, but who could not strictly be said to be in the lighting industry. The toast of the Guests was proposed by Mr. H. Punter and the reply on behalf of the guests was made by Mr. L. G. Applebee who deputised at short notice for Mr. David Scase, Director of the Manchester Library Theatre.

FORTHCOMING EVENTS

LONDON

December 10

Sessional Meeting. "TV Studio Lighting Equipment," by K. R. Ackerman. (At the Federation of British Industries, 21, Tothill Street, S.W.1.) 6 p.m.

CENTRES AND GROUPS

December 3

STOKE-ON-TRENT.—"The Lighting of Small Factories," by J. S. McCulloch. (At the North Stafford Hotel.) 6 p.m.

December 4

EDINBURGH.—"Acrylic Plastics in Modern Interior Lighting," by P. H. Collins. (At the Y.M.C.A. Social Room, 14, St. Andrew Street, Edinburgh.) 6 p.m.

NEWCASTLE UPON TYNE.—"The Lighting of London Airport," by J. G. Holmes. (At the large Lecture Theatre, Grey Hall, Dept. of Electrical Engineering, King's College, College Road, Newcastle upon Tyne, 1.) 6.15 p.m

SWANSEA.—"Road Vehicle Lighting," by K. J. Jones. (At the Demonstration Theatre, South Wales Electricity Board, The Kingsway, Swansea.) 6.30 p.m.

December 5

CARDIFF.—"Road Vehicle Lighting," by K. J. Jones. (At the Demonstration Theatre, South Wales Electricity Board, The Hayes, Cardiff.) 6 p.m.

GLASGOW.—"Acrylic Plastics in Modern Interior Lighting," by P. H. Collins. (Joint meeting with A.S.E.E.) (At the Lighting Service Bureau of Scotland, 29, St. Vincent Place, Glasgow, C.1.) 6.30 p.m.

NOTTINGHAM.—"A Feminine Viewpoint on Domestic Lighting," by Mrs. K. Hudson. (At the Demonstration Theatre, East Midlands Electricity Board, Smithy Row, Nottingham.) 6 p.m. Refreshments 5.30 p.m.

December 9

LEEDS.—"Turning Day into Night—Some Interesting War-time Secrets," by C. H. Wood. (At the Lighting Service Bureau, 24, Aire Street, Leeds, 1.) 6.15 p.m. Refreshments from 5.30 p.m.

December 10

LEEDS.—"Commercial and Industrial Lighting," by J. C. Harcourt. (At the Yorkshire Electricity Board, Ferensway, Hull.) 6.30 p.m. Refreshments from 6 p.m.

December 16

LIVERPOOL.—"Lighting and Coal Mining," by W. E. Mangnall. (At the Committee Rooms of the Liverpool Passenger Transport Office, 24, Hatton Garden, Liverpool, 3.) 6 p.m.

December 19

MANCHESTER.—"Lighting for Photography," by R. W. Unwin. (At the Demonstration Theatre, N.W. Electricity Board, Town Hall, Manchester, 2.) 6 p.m. Refreshments from 5.30 p.m.

December 20

BIRMINGHAM.—"New Light Sources," by F. Jackson. (At Regent House, St. Phillip's Place, Colmore Row, Birmingham.) 6 p.m.

Lighting Abstracts

For the benefit of those wishing to obtain articles mentioned in "Lighting Abstracts" the following list gives the full title of journals referred to and the addresses at which they are published. The addresses given are believed to be correct but no guarantee in this respect can be given.

All articles or papers abstracted are understood to be generally available. Unless otherwise stated in the abstract the language in which the article or paper is written is English.

Copies of articles or papers cannot be supplied from the offices of *Light and Lighting*.

Bull. Soc. Franç. Elect.	*Bulletin de la Société Française des Electriciens*, 8-14, Avenue Pierre Larouse, Malakoff (Seine), France.
Bull. Assoc. Suisse Elect.	*Bulletin de l'Association Suisse des Electriciens*, Seefeldstrasse 301, Zürich 8, Switzerland.
Byggmästaren	*Byggmästaren*, Kungsgatan 32, Stockholm, Sweden.
Electrical Construction and Maintenance	*Electrical Construction and Maintenance*, 330, West 42nd Street, New York 36, New York, U.S.A.
Elektro-Post	*Die Elektro-Post*, Verlagsort (13b), Mindelheim, Germany.
Elektrotech. Zeits. (B)	*Elektrotechnische Zeitschrift (Ausgabe B)*, Brillerstrasse 99, Wuppertal - Elberfeld, Germany.
Elettrotecnica	*Elettrotecnica*, Associazione Elettrotecnica Italiana, Via S. Paolo 10, Milan, Italy.
Illum. Engng.	*Illuminating Engineering*, The Illuminating Engineering Society, 1860, Broadway, New York 23, New York, U.S.A.
Int. Ltg. Rev.	*International Lighting Review*, P.O. Box 784, Amsterdam, Netherlands.
J. Opt. Soc. Am.	*Journal of the Optical Society of America*, American Institute of Physics, 57, East 55th Street, New York 22, New York, U.S.A.
Lichttechnik	*Lichttechnik*, Eichborndamm 141-167, Berlin-Borsigwalde, Germany.
Ljuskultur	*Ljuskultur*, Sveavagen 28-30, Stockholm, Sweden.
Lux	*Lux*, 108, Rue Denfort Rochereau, Paris (VIIIe), France.
Philips Res. Rep.	*Philips Research Reports*, Century House, Shaftesbury Avenue, London, W.C.2.
Rev. gen. Elect.	*Revue Générale d'Electricite*, 12, Place Henri-Bergson, Paris (VIIIe), France.
Trans. Illum. Eng. Soc. (London)	*Transactions of the Illuminating Engineering Society*, The Illuminating Engineering Society, 32, Victoria Street, London, S.W.1.
Trans. S. African Inst. Elect. Engrs.	*Transactions of the South African Institute of Electrical Engineers*, Kelvin House, Marshall and Holland Streets [P.O. Box 5907], Johannesburg, South Africa.

POSTSCRIPT By 'Lumeritas'

IF I had been asked a month ago to guess how many there are of public authorities responsible for the lighting of our roads my guess could not have been more definite than "a large number." Now, however, guessing is unnecessary, for Mr. Granville Berry—who is president-elect of the APLE and is also the Coventry City Engineer and Surveyor—has said that the number is nearly 3,500! No wonder Mr. Berry has made a plea for fewer highway lighting authorities because, with so many fingers in the pie, it is difficult to achieve that uniformity and continuity in lighting that he regards as essential for safety on trunk roads. The full cost of lighting these "national" roads should be borne by the central Government, said Mr. Berry in a paper recently read to the Institution of Highway Engineers. At present, only half the installation cost is provided by the Ministry of Transport, but there are sections of these roads for which local authorities are responsible who cannot afford to contribute even half the cost of lighting them. Another interesting figure given by Mr. Berry was that of the sum spent on trunk road lighting since the war—£1,750,000. This may seem a lot of money but it is only a small percentage of the total sum wasted on abortive national projects during the same period.

BACK in September when the IES of the USA held a National Technical Conference in Atlanta, one of the most interesting papers presented was that by G. W. Clark and R. E. Harz. The authors chose for their title "Foot-candles, Foot-lamberts—What next?" And "what next" turned out to be chiefly change or variability as a designed feature of lighting. Recalling Weston's paper on "Visual Fatigue" read at the 1953 National Technical Conference in New York (and to the British IES at the end of the previous year), the authors said that "its most challenging aspect from the standpoint of the illuminating engineer was that section which had to do with visual boredom" and which suggested that, where artificial lighting has to be used continuously in work spaces, it should not be static but vivified by being "suitably variable though constantly adequate." The authors set out to meet this challenge by creating an installation which would not only vary the distribution of brightness and the working illumination automatically with a suitable rate of change, but would also bring about colour changes as suggested by Strange and Hewitt in their 1956 paper on Light and Colour in Daily Life (Trans. IES, London. **21,** 255). The visible part of the installation was a "translighted ceiling." Subtle and non-distracting changes of colour pattern were produced by motorised lighting units above the plastic ceiling and supplementary to the main light sources. The illumination level was also varied without distraction and observation of the behaviour of the room occupants indicated that the changes had favourable effects. The illumination was adequate at all times, the minimum being "40-50 ft.c." and the maximum "100-110 ft.c." The authors did not ignore the question of installation cost but reached the conclusion that a "dynamic" system which provides for variable spectral quality of the light, variable brightness distribution and variable level of illumination costs about 60 per cent. more than a completely static system. They think, however, that—say in an office—it may be more rewarding to incur this additional cost to obtain "dynamic" lighting rather than to incur it in boosting the illumination level with "static" lighting. So do I.

HOW inconsistent can people be? Many and loud have been the protests against concrete lamp standards in streets of a bygone age. Yet there are occupants of contemporary houses who have actually erected old gas street lamp standards—converted to take an electric lamp—in their front gardens to do duty for "approach" lighting. Do these out-dated lamp-posts and lanterns harmonise with houses of contemporary design any better than contemporary lamp standards harmonise with "period" houses? Is their design so happy that they nowhere look incongruous? I do not think so; but perhaps contemporary starkness is more acceptable to some people if there is coupled with it some relic of the past, even if this relic is out of character. Perhaps psychiatrists would "explain" this cult as an expression of unconscious revolt against a too thorough-going rejection of the "traditional" in the formulation of the "contemporary," or as regression to an infantile "fixation"! Be this as it may, it seems that museums are not to be the only repositories of those pieces of street furniture which, in the "good old days," frequently lent temporary support to the "well-oiled" reveller in the course of discharging their beaconic function!

ALL of us know what "dark-adaptation" means—that it is the process by which our eyes become increasingly sensitive to light (though not increasingly acute) as the level of illumination diminishes. When the process is complete we are able to see—after a fashion—in a light much more feeble than the light-adapted eyes require. It takes about an hour for the eyes to become completely dark-adapted, but this does not mean that we can then see in complete darkness—even the cat, who is said to be able to "see in the dark," cannot do this. What it means is that we have to be in a dark environment for about an hour before the eyes become as sensitive to light as they ever will be, and then we can see crudely with astonishingly little light. Now, apropos dark-adaptation, it seems such a far cry from eyes to lettuce seeds that you may well doubt whether it is not more rational to "talk of cabbages and kings" than to couple such different things. Yet it appears, from some radio gardening hints to which I listened recently, that, in a manner of speaking, lettuce seeds can be said to undergo a kind of dark-adaptation. Not that the process enables them to "see" in dim light, but, apparently, it does enable them to germinate with very little light. What was said was that new seeds require a fair amount of light for germination, but old seeds, e.g., those kept for two-three years, generally in a dark place, will germinate successfully with much less light. This may be well known to gardening enthusiasts, but it was news to me.

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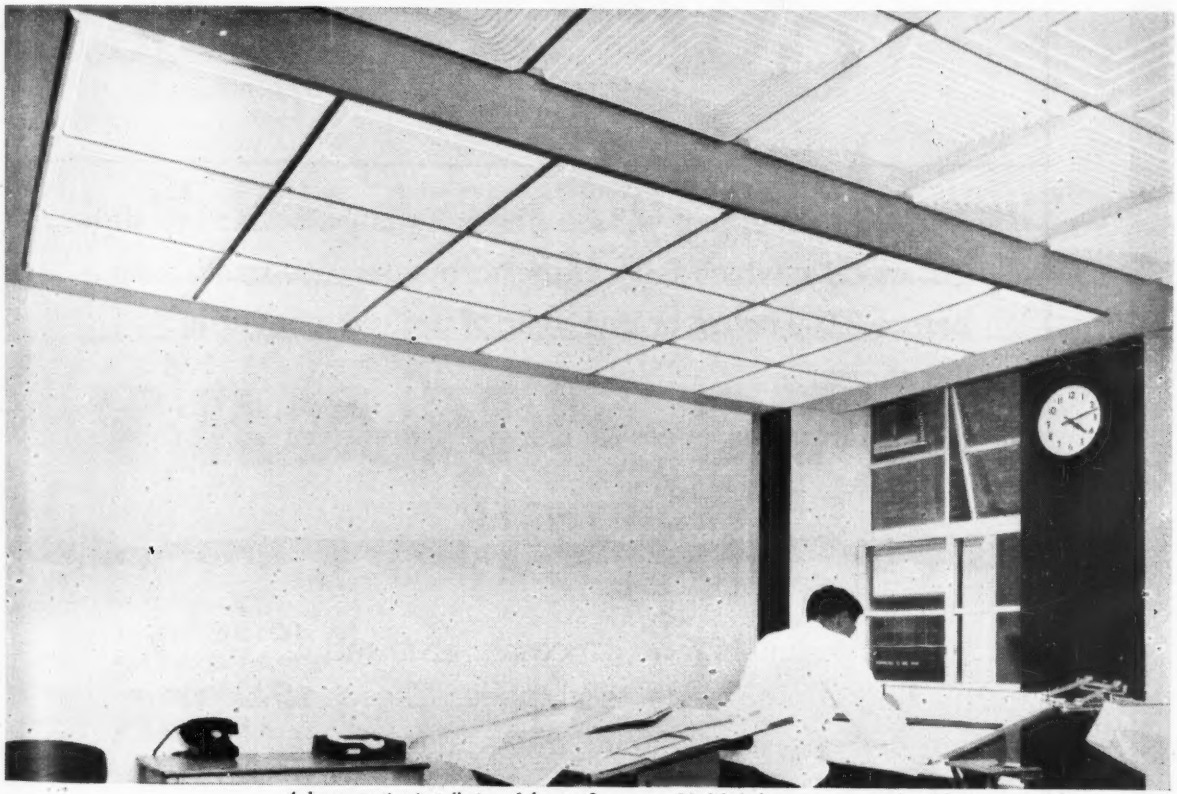

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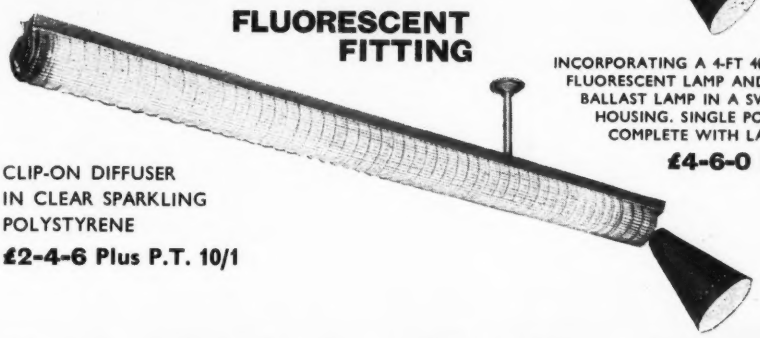

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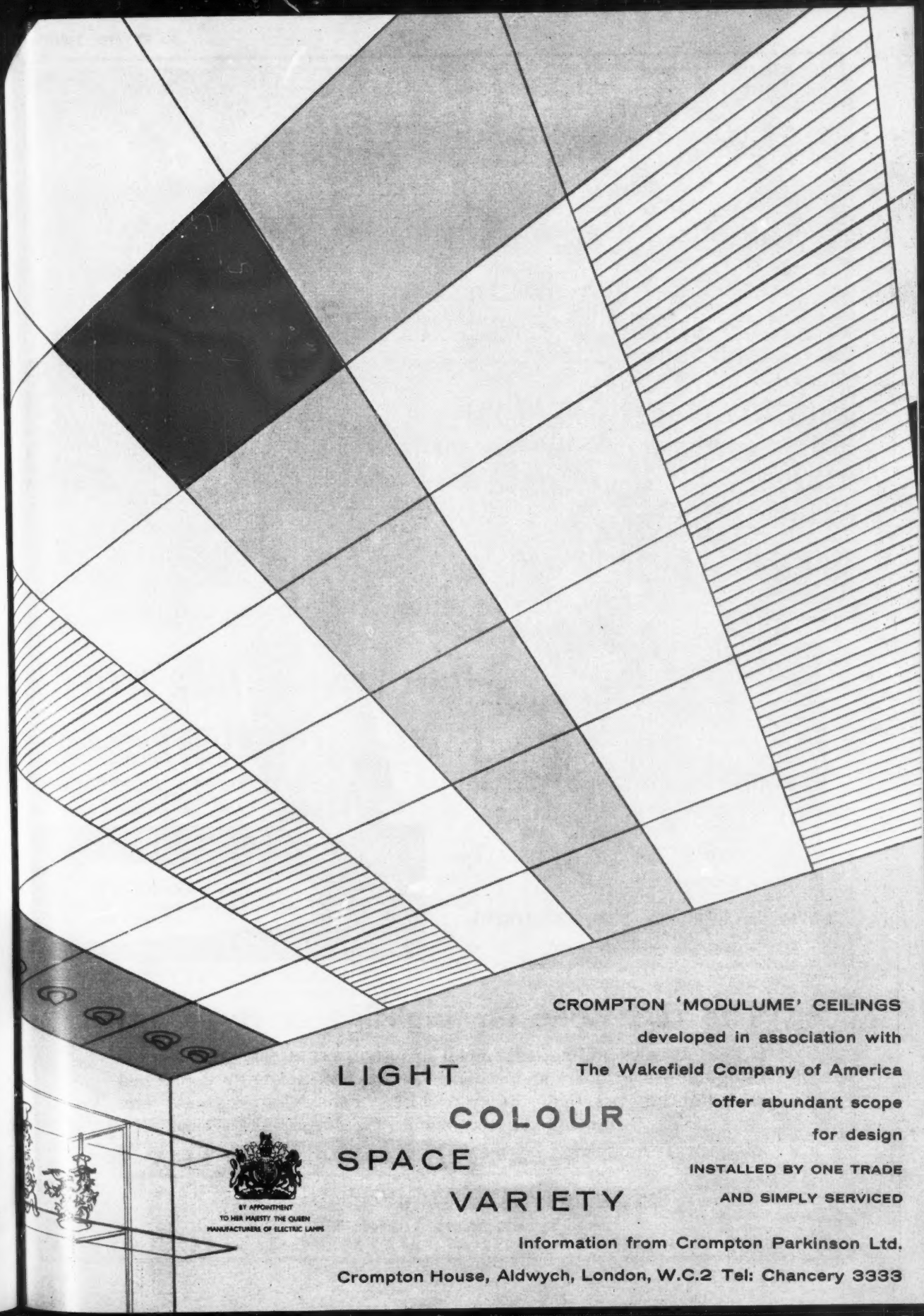

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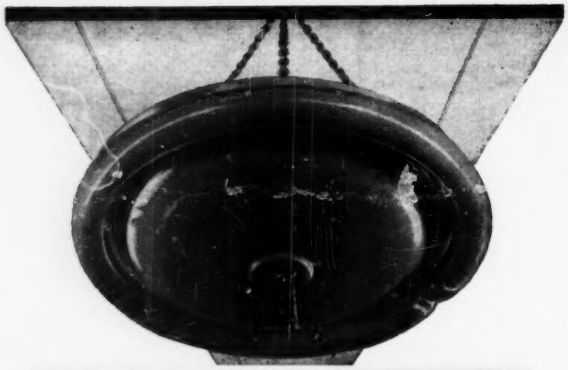

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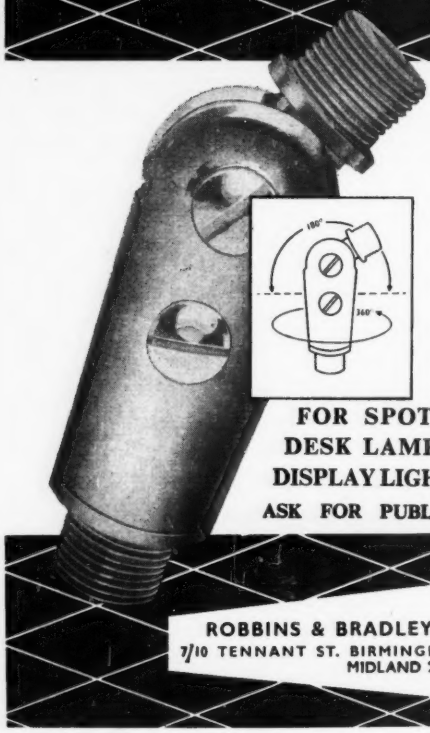

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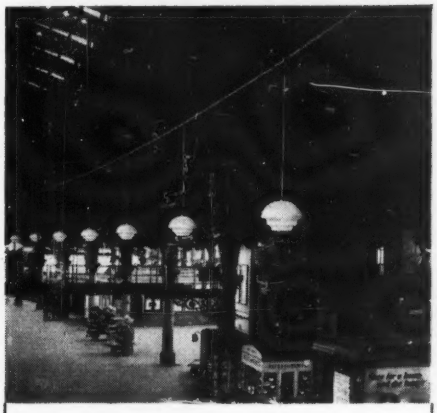

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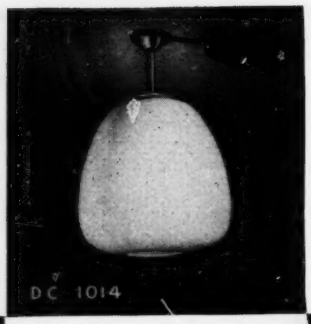

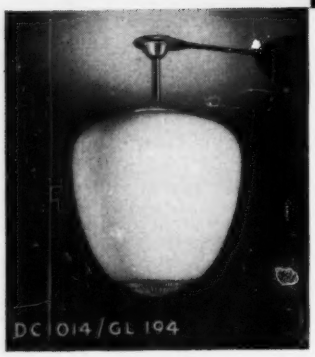

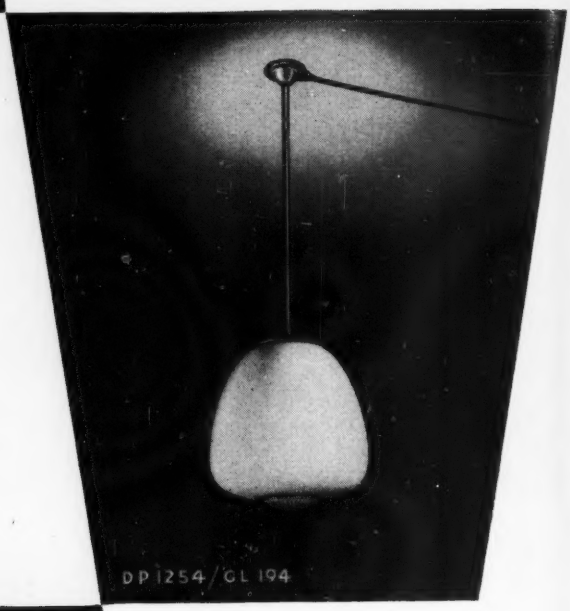

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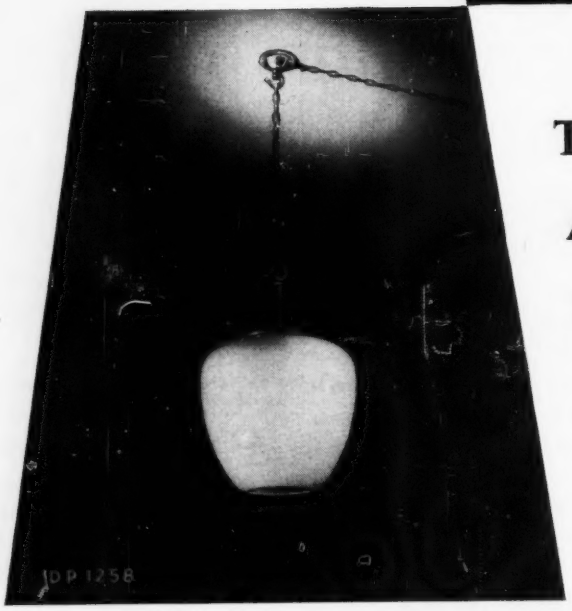

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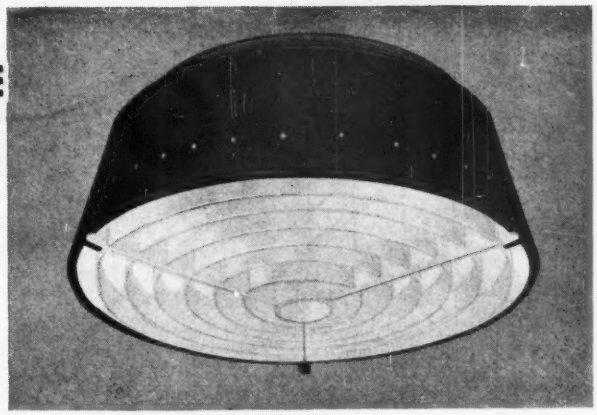
DESIGNED by Designers for Designers

These fittings are specially made for Gymnasium and Assembly Hall lighting and are made entirely of metal and finished in best quality stoved white enamel. The exterior of the reflector is available also finished in any specified B.S.S. colour.

Considerable numbers of these fittings have been installed in various schools throughout the country.



Cat. No. C354. 16″ dia. x 7¾″ deep with concentric louvre hinged for security and to render easy access to the interior for cleaning and re-lamping. The Rockbestos wiring and lamp connections are housed in a special pattress and the whole fitting is so well ventilated that failure of lamps and connections due to heat is entirely eliminated. Each fitting has three BC lamp holders fixed and wired to hold 3-100w. lamps in the vertical position.

The reflectors may be pattern pierced as illustrated or slotted for ceiling illumination if so desired.

The list price of £8. 12s. 0d. is extremely competitive for an exceptionally well made and efficient lighting fitting.

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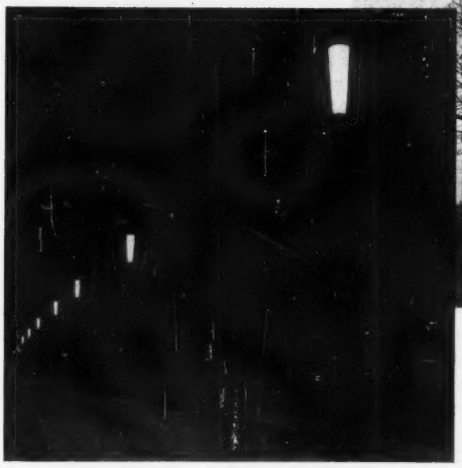
a light on time . . .

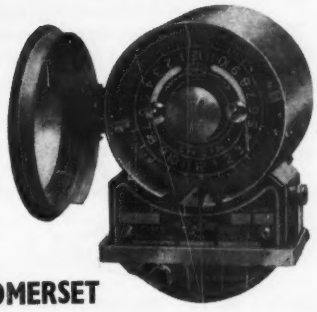
Complete automatic control of street lighting is achieved with Horstmann Time Switches. The switches can be set to light up the circuit at a given time, reduce main lighting at or about Midnight when traffic is less and full lighting is not essential, and finally to switch OFF at dawn.

A full range of HORSTMANN Time Switches is available to meet all the demands of Public Lighting control, and 50 years of design and manufacturing experience ensure unfailing reliability under varying conditions of service.



A section of the lighting scheme installed at Crawley, controlled by Horstmann Time Switches.

Photographs by courtesy of Crawley Development Corporation.



. . . HORSTMANN TIME SWITCHES

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Here at last is an all-purpose design for outdoor lighting that is both practical and elegant. The original lantern was chosen for lighting the new oil town of Kuwait in competition with British and foreign manufacturers. This successful design forms the basis of the Kuwait Unitary System which provides for every category of lighting from civic centres and main roads down to secondary roads and housing estates. The system is completely flexible and employs a high proportion of standardised and interchangeable parts and fittings. It makes possible completely harmonised lighting schemes on any scale; it covers every size and arrangement of outdoor lighting, and it allows for modification to suit changing conditions.

Maintenance is simple and there is no need to carry a wide variety of spares and replacements. The Kuwait Range has been approved by the Council of Industrial Design for inclusion in Design Review and is already widely used in the United Kingdom and overseas. If you would like complete information about the Kuwait Unitary System, write for leaflet F.27 or get in touch with your local Siemens Ediswan lighting engineer for advice—no obligation.

Regd. Design No's 875686, 878142

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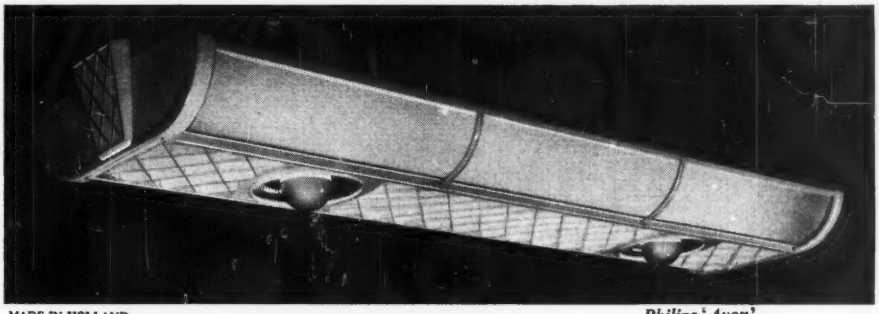

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The General Electric Co. Ltd. were awarded this contract for the supply and erection of all the equipment and completed the installation, in collaboration with the London Electricity Board, in time for the switch-on.

This scheme for the City of Westminster which extends from Oxford Circus to Piccadilly Circus uses G.E.C. "Four-Eighty" lanterns each equipped with four 5 ft. 80 watt instant start Osram Warm White fluorescent tubes. The lanterns are mounted on steel columns fitted with ornamental cast iron bases specially designed for the City Council. Special post top "Four-Forty" fluorescent lanterns are used on the centre islands.

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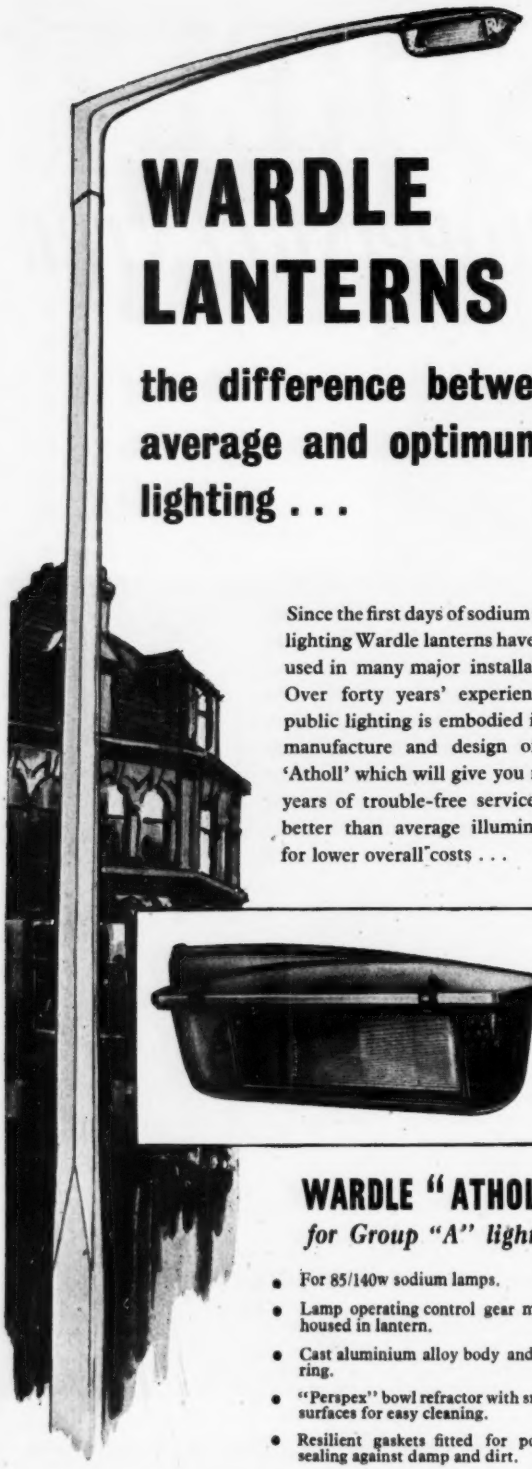

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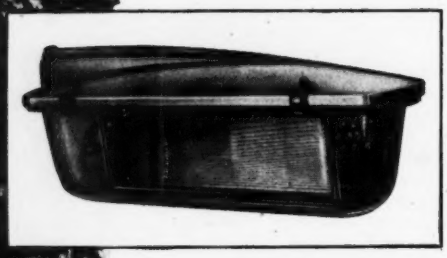

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Stanton Type 8 Prestressed Spun Concrete Lighting Columns at Banbridge, County Down.

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The present Lighting Service Bureau for the Mid-East England Area was officially opened by the Lord Mayor of Leeds in September, 1949. It serves a part of the country in which the manufacture of textiles is dominant and can take credit for many improvements in the lighting of that industry. The photograph shows part of the lecture theatre, with mannequins and fabrics, on the occasion of a visit from the press.

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